ACQUISITION OF STUDY REPORTS FOR LITERATURE REVIEW OF HORIZONTAL WELLS AND MODELS FOR HORIZONTAL WELL INJECTORS AND PRODUCERS.

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PART 2

MICROMEDIA

HORIZONTAL WELL TECHNOLOGY FOR OIL SANDS

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TABLE OF CONTENTS

1 FOREWORD.. 3

2 SCOPE OF SERVICES.................................. 4

3 SUMMARY & RECOMMENDATIONS........................... 5

4 INTRODUCTION..................................... 7

5 BRIEF HISTORY OF HORIZONTAL WELLS FOR HEAVY OIL PRODUCTION.8

6 HORIZONTAL WELL DRILLING TECHNOLOGY......................10
  - Introduction 10
  - Long Horizontal Well Drilling 10
  - Drainhole Drilling 12
  - Comparison of Bechtel and Texas Eastern Technologies 15

7 APPLICATION OF HORIZONTAL WELLS TO OIL SANDS AND HEAVY OIL.18
  - Introduction 18
  - Field Tests 18
  - Esso's Horizontal Well in Cold Lake 18
  - Surmont Project, South Athabasca 23
  - Yarega Mine, U.S.S.R. 23
  - Baku Area Fields, U.S.S.R. 26
  - The "Hot Plate" Project, California 27
  - Other Horizontal Well Field Tests 27
  - AOSTRA's Underground Test Facility (UTF) 30
  - Oil/Bitumen Production Processes Based Upon Patents 34

8 LABORATORY STUDIES OF OIL SANDS..........................35
  - Introduction 35
  - Models Used 35
  - Observations 38

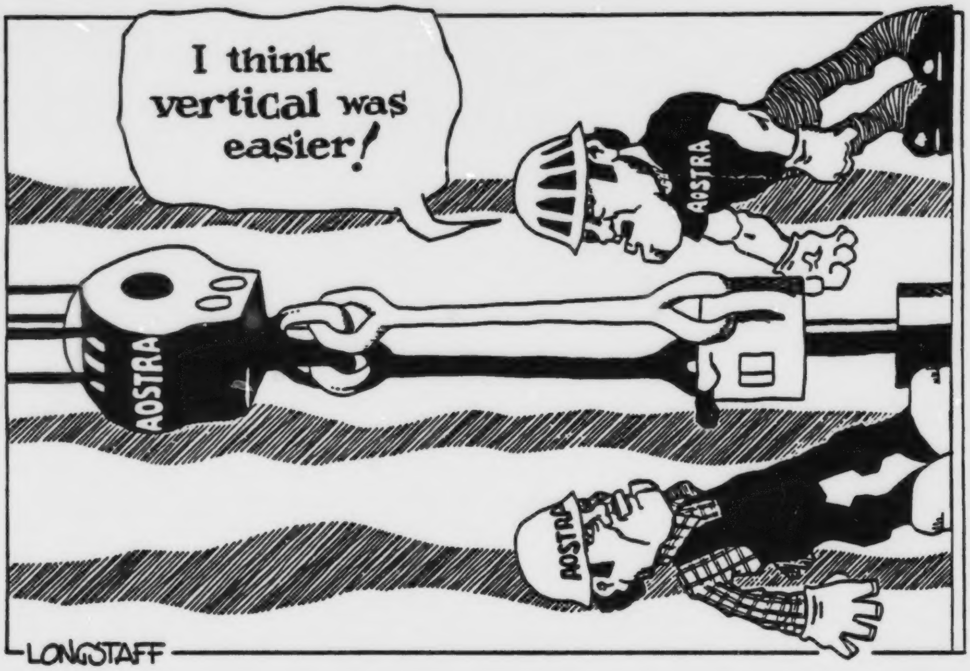
9 THEORETICAL STUDIES OF HORIZONTAL WELLS..................40
  - Introduction 40
  - Isothermal Gravity Drainage Models for Horizontal Wells 40
  - Non-Isothermal Gravity Drainage 41
  - Numerical Simulation of Horizontal Wells 42
    - Steamflooding 42
    - Steam Assisted Gravity Drive 47
  - Observations 47

10 RECOMMENDATIONS AND DISCUSSION............................50

11 BIBLIOGRAPHY.......................................53

APPENDIX A: SUMMARIES OF HORIZONTAL WELL PATENTS.............60

EXHIBIT 1: ILLUSTRATIONS OF BECHTEL & TEXAS EASTERN METHODS
EXHIBIT 2: COPIES OF THE REFERENCES CITED
EXHIBIT 3: COPIES OF THE PATENTS CITED


I think vertical was easier!
AOSTRA
AOSTRA
AOSTRA
LONGSTAFF

FOREWORD

This survey of horizontal well technology, as applied to oil sands, was initiated by Mr. Walter Seyer and Dr. D.E. Towson in May, 1986. The first draft was approved in November, 1986. Copies of the references cited, and those of the patents dealing with horizontal wells are contained in Exhibits 2 and 3.

I wish to thank Mr. Seyer for his frequent comments and observations during the course of this study, and Dr. Towson for his helpful suggestions. This survey was a valuable experience, for which I would like to thank PetroCanada.

SCOPE OF SERVICES

Consultant shall provide the personnel to undertake the Work which includes, but is not limited to, the supply of the following services:

1. OBJECTIVE

Consultant shall perform a literature study and conceptual analyses of horizontal wells in bitumenous oil sands. All relevant public information and experience are to be summarized and assessed. Based on the information and concepts developed, major problems are to be highlighted and experimental and theoretical analyses other than field tests recommended. The objective of the recommendations and study is to improve the understanding, prediction, and possibly the control of the horizontal well process.

2. LITERATURE STUDY

The study is not be restricted to any particular geographical region, process or functional aspect of horizontal wells. The survey should include the widely known literature from Europe, including U.S.S.R., the United States and Canada and any area where studies or results have been documented. Horizontal wells from the surface must be considered in addition to the wells drilled from shafts or tunnels. The Bechtel Horizontal Drilling Process (HDP) is to be included. All information and analyses on the completion and operation and the wellbore and reservoir flow are to be covered.

3. ASSESSMENT

Major problems and unknowns are to be identified and clearly described. While significant aspects are highlighted, all of the elements of the potential processes in the injection and production mode must be considered. This study will be based mainly on conceptualizing and information gathering rather than quantitative computer or analytic solutions. Recommendations are to be directed to furthering the study.

4. RECOMMENDATIONS

Recommendations would be directed to reducing uncertainties and comparing alternatives. Scaled physical models and numerical simulation could be recommended; however these should be presented to advance the state of the art. Refinements in the computer modelling for example might include an improved wellbore relationship or grid block orientation. Recommendations for laboratory models should include the essential parameters that would be scaled.

SUMMARY AND RECOMMENDATIONS

Horizontal wells have been employed for over 50 years for gravity oil drainage in oil mining operations, although such applications have been of limited scope, i.e. in shallow reservoirs, with light oils, where economic conditions favoured such development. In oil sands, the use of horizontal wells is new: altogether no more than 10 wells have been drilled, only two of which are currently in operation. This does not imply that horizontal wells do not have a role in the in situ exploitation of oil sands of Alberta. Rather, it is a reflection of the current economics. The oil sands experience has established the superiority of horizontal wells over vertical wells for gravity drainage of oil, once it is mobilized by steam. Thus horizontal wells are primarily used as producers, although they could be injectors as well in a carefully designed steamflood type process, as shown by numerical simulation results.

Drain holes, or short (around 100 m) horizontal wells radiating from a vertical well have been employed extensively in California, and have been shown to be cost-effective. Such wells can be efficient producers, if the in-place oil is sufficiently mobile. Since they rely on gravity flow of heavy oil with or without thermal stimulation, they have limited application in the oil sands of Alberta. AOSTRA's Underground Test Facility will provide valuable information in this regard. The key to oil recovery in Cold Lake, and especially Athabasca, is extensive thermal stimulation of bitumen, employing vertical/horizontal well combinations. Once adequate mobility has been attained, horizontal wells may be used for bitumen drainage. Horizontal wells have not been successful as steam injectors in oil sands, but this may change in view of the new developments.

Very few laboratory studies of horizontal wells have been reported thus far. The experimental results are of qualitative value only. The emphasis is on gravity drainage of oil into a horizontal conduit. Except for one study, the experiments were unscaled. Particularly lacking is the proper representation of flow around the wellbore.

A number of analytical approaches to flow into horizontal wells, under both isothermal and non-isothermal conditions, have been published. These are of necessity over-simplified, but useful for obtaining an estimate of the response. Experimental results were only in fair agreement with calculations in one case.

Several numerical simulation studies of horizontal wells have been published. In all cases, a conventional thermal simulator is employed, with the wells laid out horizontally. No account is taken of flow asymmetry around the well.

RECOMMENDATIONS

Horizontal well drilling technology has been developed to a point where it is feasible to employ such wells in large scale pilots in the oil sands. Texas Eastern and conventional horizontal well technologies appear to be appropriate for the oil sands.

Horizontal wells have been more successful as producers rather than steam injectors. Considering the high cost of drilling and testing such wells, attempts should be made to purchase or exchange field data with other operators. A meaningful field test should employ several horizontal wells to observe the variability of response.

Laboratory studies of horizontal wells should be based upon suitable scaling criteria, yet to be derived. Two types of models should be employed: pattern flood models incorporating horizontal and vertical well combinations, and wellbore models to determine flow characteristics in the wellbore vicinity. Features such as pressure drop in the well, completion interval, steam quality change over length, should be accounted for.

Numerical simulation of horizontal/vertical well combinations can provide useful comparative information on the efficiencies of various combinations. Again, a proper representation of flow into (or out of) a horizontal well is needed for reliable results.

The above recommendations are discussed in Chapter 10.

INTRODUCTION

Horizontal wells have gained a great deal of importance in the last 10 years. With the growing emphasis on heavy oil recovery, application of horizontal wells in oil sands (or, tar sands, in the U.S.A.) and heavy oil reservoirs is the subject of many papers and research studies. However, the actual testing of horizontal wells in such reservoirs is still quite limited: very few horizontal wells have been drilled in the oil sands of Alberta, and in the heavy oil formations of Lloydminster area. Undoubtedly, there are several plans to carry out horizontal well tests in the oil sands, and it seems that horizontal wells have a place in the long term development of oil sands. The production efficiency and cost-effectiveness of such wells remains to be seen. The few wells tested so far are hardly enough to make any generalizations.

Other applications of horizontal wells and variations thereof have been carried out in light and medium gravity oils, with the diverse purposes of increasing productivity, delaying water cone formation, carbon dioxide injection, etc. This report will primarily summarize applications of horizontal wells to oil sands and heavy oil formations, with only passing reference to other applications.

Numerical simulation studies of horizontal wells have been reported by many investigators, showing favourable response in most instances. Such studies still lack a proper representation of a horizontal well insofar as flow around the well is assumed to be radial. Laboratory studies are few and far between for reasons of difficulty of modelling and scaling.

This study summarizes the current knowledge concerning the application of horizontal wells to oil sands and heavy oils, with suggestions regarding laboratory and theoretical studies.

BRIEF HISTORY OF HORIZONTAL WELLS FOR HEAVY OIL PRODUCTION

Mining of oil, as contrasted with conventional drilling was considered as far back as 1920s, when an inclined shaft was sunk 500 ft (160 m) into an oil sand at Newport Beach, Calif. Even before, in 1866, Union Oil bored 31 oil drainage tunnels, up to 1,900 ft (600 m) long, in Ventura County, Calif. Many other early applications of horizontal wells and Mines are cited by Sinor (1), both in the U.S. and in other countries, notably France, Germany, and Japan. The U.S. Bureau of Mines Bulletin 351, entitled "Mining Petroleum by Underground Methods" was published in 1932 (2), proposing various techniques. Such methods employ horizontal wells or conduits in some form or other. This study was updated in 1978, by Energy Development Consultants (3).

The best known earliest application of inclined wells and mining methods to heavy oils is the Yarega field (discussed in Chapter 8) in the U.S.S.R., 1300 km northeast of Moscow. Many other applications of this type have been discussed in several voluminous publications, notably the two-volume study, "An Evaluation of Heavy Oil Mining", by Piper, Riddel and Trent, published by the U.S. Dept. of Energy, in 1983 (4), and "Light Oil Mining in United States", by Albayrak and Protopapas, published by U.S. DOE, in 1984 (5).

Turning to oil sands of Alberta, the use of mining methods and horizontal wells is relatively new. A review of these activities was given by Harding and Farouq Ali (6). During 1978-1981, Petro-Canada operated a project, called MAISP (Mine Assisted In Situ Project), in collaboration with Canada-Cities Service Ltd. (now Canadian Occidental), Esso Resources Canada Ltd., and Gulf Canada Ltd., demonstrating that long horizontal wells can be successfully drilled, completed and operated in oil sands.

Esso Resources Canada Ltd. have drilled two horizontal wells in the Cold Lake region, 330 and 1000 m in length, which are being tested. Texaco drilled three horizontal wells in Athabasca, producing as much as 100 m3/day in a steam-based recovery process, although sand production was a persistent problem. Several horizontal wells are in the planning stage.

A somewhat different approach to horizontal wells has been pursued in California, where "drainholes", often 200 to 300 ft (60 to 100m) in length, are drilled radially outward from a vertical well, in a wheel spoke pattern. Two companies have developed this technology. A drainhole was drilled by Murphy Oil Co. in Lloydminster, with discouraging results. It appears that it has not been tested in the oil sands areas.

Outlook

Horizontal wells have generated a great deal of interest in the oil industry. Several field tests are in the planning stage in the oil sands as well as the Lloydminster heavy oil area. Much progress has been made in the develpment of horizontal well drilling technology. The oil recovery techniques based upon horizontal wells are still open to question, because so few horizontal wells have been drilled and tested. Speculation regarding oil production efficiency of horizontal wells is based upon mathematical simulation studies; even laboratory studies reported thus far are few. A second area of concern is economics of horizontal well drilling and operation, which is related to the question of oil recovery. Many ideas in horizontal well-based oil recovery processes have been advanced, as evidenced by the patent literature. Clearly, horizontal wells would play a role in oil recovery from the oil sand of Alberta.

HORIZONTAL WELL DRILLING TECHNOLOGY

Introduction

The earliest horizontal wells were drilled by boring methods typical of mining operations. Stromont (1953) (7) and Eastman (1954) (8) have given a description of the tools and techniques used for lateral drainhole drilling. In recent years, several publications have discussed the technology of horizontal well drilling, in the context of (i) Esso's Cold Lake wells, (ii) Texaco's Athabasca wells, (iii) Elf Aquitaine's horizontal wells in Europe, and (iv) Drainholes drilled in California and elsewhere. In the following, a brief description of the drilling methods will be given; details can be found in the original papers appended.

Long Horizontal Well Drilling

Elf Aquitaine and Institut Francaise du Petrole (IFP) (9) have published numerous papers on the technology and the efficacy of horizontal wells. Giger (1982) (9), Giger and Jourdan (1984) (10,11), and Reiss (1985) (12) have discussed the drilling of four wells in Europe. These wells were drilled at depths of 600 to 3000 m in consolidated formations. The Rospo Mare well, offshore Italy, is the only one producing a viscous oil (12 API) from a limestone formation. A combination of ordinary drill bits with bent subs and downhole mud motor was used to drill a 600 m long well at 2000 m depth. A slotted liner was inserted in the hole. A special logging technique was developed. Baron and Wittrisch (1982) (13) give relevant details. In another instance, a high water producing zone was successfully blocked off by cement in a 330 m long horizontal well, Lacq 91, in France (Giger, 1982 (14); Dorel,1983 (15)).

Horizontal well drilling in shallow oil sands of Athabasca poses special problems. With depths on the order of 120 to 600 m, kicking off from a vertical to horizontal position will require a long radius, using conventional drilling techniques. Texaco solved this problem by the use of a slant rig. The rig was positioned at an angle of 45 deg, and was used to drill three horizontal wells, each 300 m long, at a depth of 126 m. Pugh (1982) (16,17) and Loxam (1982) (18,19) describe the drilling method using a hydraulically powered drilling rig.

Pacholko and Vaughan (1984) (20) described the use of a slant rig for drilling wells at Fort Kent, Cold Lake. At the depth of 350 m, to develop a sufficient area at the 2 ha (5 acres) spacing would have required a high angle buildup rate (5 deg/30 m), resulting in an unacceptable bottomhole angle (up to 84 deg). Figure 1 illustrates the benefit of slant rig in this instance. A 4 ha pad permitted drilling a cluster of 32 wells, developing 65 ha. Slant drilling rigs are extensively used for drilling in offshore Peru and California (Ward, 1984 (21)). The rig used at

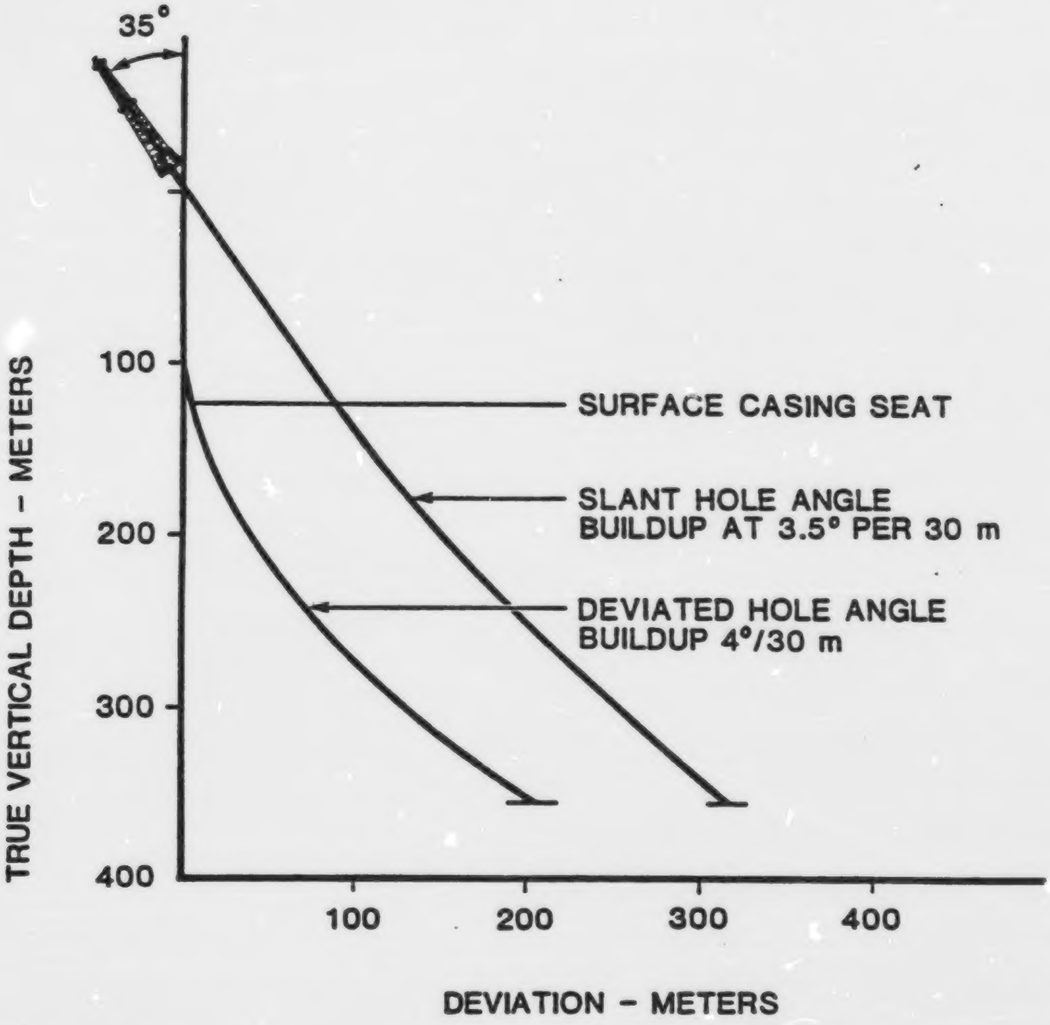


Fig. 1 - Comparison of deviated vs. slant hole profiles.

Fort Kent was diesel-electric powered, fully winterized, connected by a utilidor to the mud, heating, and electric power systems, at a cost of $5.4 m.

Bezair and Markiw (1979) (22) and Baldwin, Royal and Gill (1983) (23) have described the drilling of Esso's horizontal wells at Cold Lake. The details of the second well are more fully discussed by MacDonald (1985) (25) and in the ERCB submission (1984) (24). The first well, 323 m in length, was drilled at a depth of 450 m. The second well, 1000 m in length was drilled at a depth of 466 m. A schematic of this well is shown in Fig. 2.

The first well was drilled as follows: 46 m using conventional rotary drilling, the surface casing was then set, and a bent sub was used to kick off, with a drilling angle buildup of 14 deg per 100 m, until an angle of 90 deg was reached. The survey equipment was installed on a non-magnetic drill collar, located away from the bit. During drilling, the vertical depth of the horizontal section was controlled to within 0.1%, but in the lateral direction control was only within 2%, i.e. +-10 m at 500 m depth. It is proposed to use 3-d seismic methods to pinpoint the well in the horizontal plane.

Drainhole Drilling

In the last few years, significant progress has been made in drilling sharply deviated "drainholes", or radially drilled wells in the 30 to 200 m length range. There are basically two drilling technologies for this range: the Bechtel and the Texas Eastern methods. The Bechtel method is discussed in detail by Pendleton and Ramesh (1985) (26,27), Dickinson and Dickinson (1985) (28), Rintoul (1985) (29), and Dickinson, Anderson and Dickinson (1986) (30). Figure 3 shows how relatively short radial drainholes are drilled into an unconsolidated formation, using high pressure water jets, from an underreamed portion of a vertical well. (In a laboratory study, Gates and Toogood (1984) (31) have discussed the mechanics of jet piercing of oil sand). A 5 to 10 ft (1.5 to 3 m) window is milled into the casing and a 4 ft cavity is underreamed using water jets. A whipstock is erected at right angle at the desired depth. Next, a specially developed pipe, with water jets, is used to drill a 4 inch (10 cm) diameter hole. The production tubing is cut off, the whipstock is de-erected and re-erected at a desired angle to drill the next well, and the procedure is repeated. The production tubing can be perforated and gravel packed, as described in (26). A logging tool is also described.

The turning radius is only 30 cm in the above-described Bechtel approach. As many as 24 wells can be drilled in any particular horizontal plane. The hydraulic jet cutting rates are 3 to 30 m/min. The time required for drilling four horizontal wells in a shallow formation is less than 60 hr.

In contrast, the Texas Eastern drilling method is closer to conventional horizontal well drilling. Stramp (1980) (32),

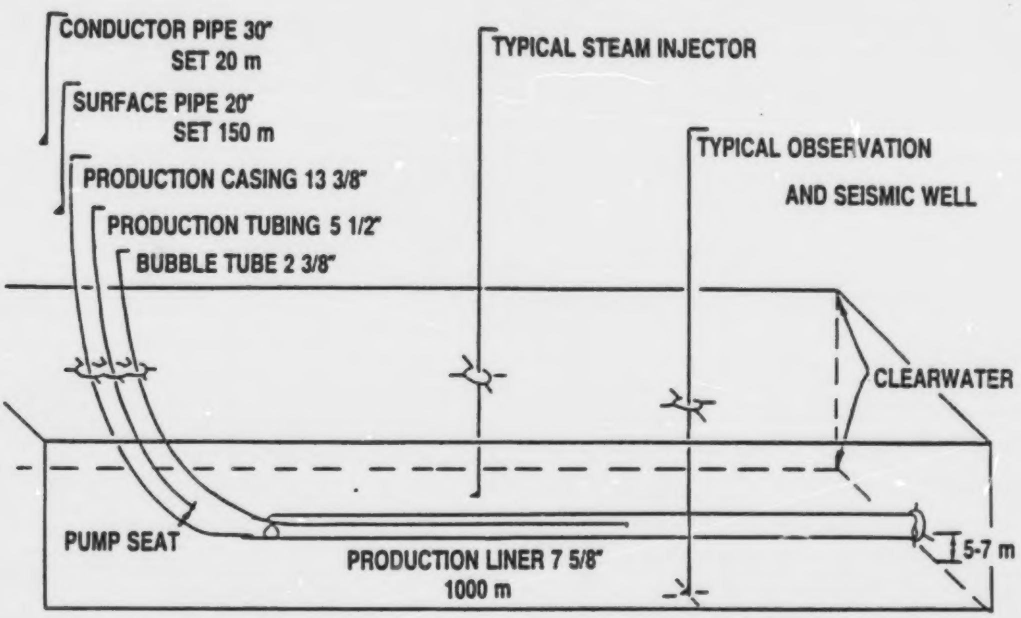

CONDUCTOR PIPE 30"
SET 20 m
SURFACE PIPE 20"
SET 150 m
PRODUCTION CASING 13 3/8"
PRODUCTION TUBING 5 1/2"
BUBBLE TUBE 2 3/8"
TYPICAL STEAM INJECTOR
TYPICAL OBSERVATION
AND SEISMIC WELL
CLEARWATER
5-7 m
PUMP SEAT
PRODUCTION LINER 7 5/8"
1000 m

Fig. 2 - A schematic of Esso's long horizontal well.

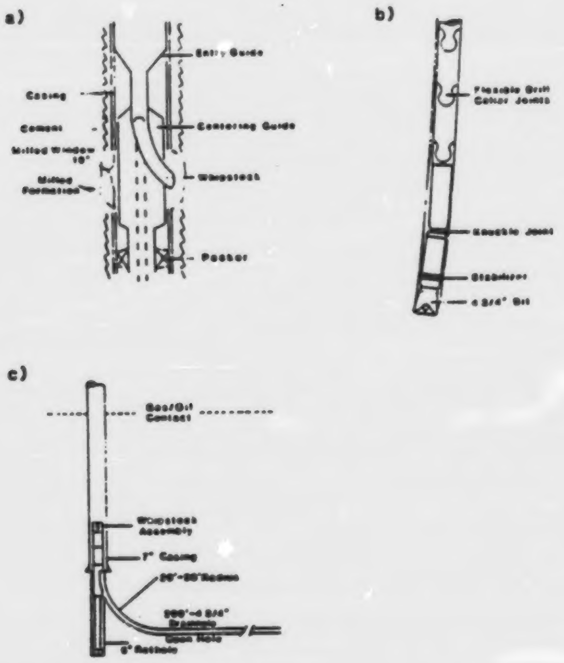

a)
Entry Guide
Casing
Cement
Milled Window
Milled Formation
Centering Guide
Whipstock
Packer
b)
Flexible Drill Collar Joints
Knuckle Joint
Stabilizer
Bit
c)
Gas/Oil Contact
Whipstock Assembly
7" Casing
Drainhole
Open Hole
Rathole

Fig. 4 - A schematic of medium length drainhole drilling: (a) whipstock assembly; (b) wiggly collars; (c) hole schematic.

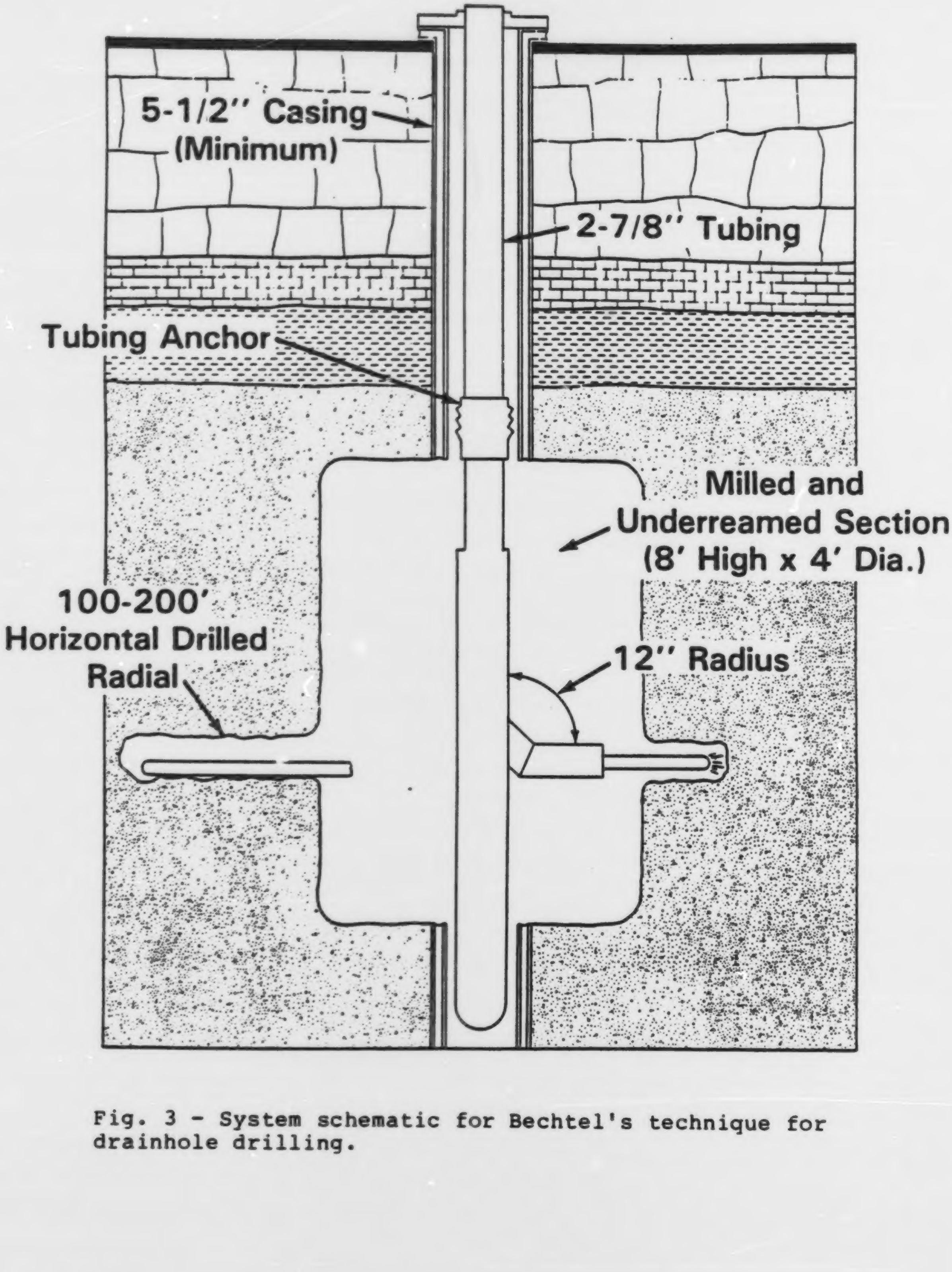

5-1/2" Casing
(Minimum)
2-7/8" Tubing
Tubing Anchor
Milled and
Underreamed Section
(8' High x 4' Dia.)
100-200'
Horizontal Drilled
Radial
12" Radius

Fig. 3 - System schematic for Bechtel's technique for drainhole drilling.

Holbert (1981) (33), and Gorody (1984) (34) have described the drilling of 60 to 200 m long drainholes through an existing vertical well. A window is cut in the existing casing by a milling operation. Then, "wiggly" collars, shown in Fig. 4, are used to drill off the whipstock and into the formation, turning 3 deg per ft (10 deg per m) with a turning radius of 30 ft (9 m). This is continued until an angle of 85 deg is reached. At that point, a second bottomhole assembly is used to drill the rest of the hole.

Holbert (33) shows that hydraulics and friction combine to limit the maximum drainhole length to 1200 ft (360 m). Texas Eastern have drilled a drainhole of this length. It is now possible to complete such a hole by inserting a slotted liner. A sufficiently small wire mesh screen can be wrapped on the liner to prevent silt and sand from entering the well.

Comparison of Bechtel and Texas Eastern Technologies

In the following, a comparison is presented of the conventional horizontal well (HW), Bechtel drainhole, and Texas Eastern drainhole drilling technologies. Esso's two horizontal wells were drilled by the conventional HW method.

Conventional HW

Advantages

1. Long horizontal interval (†1000 m).
2. Liner completion.
3. Larger hole size.
4. Re-entry and workover.
5. Favourable experience in oil sands.

Disadvantages

1. Inflexibility (basically useful for production only)
2. Large 90° curve (†200 m).
3. New surface facilities.
4. No multi-leg capacity.
5. Expensive

Bechtel Drainhole

Advantages

1. Multi-leg capability.
2. Short 90° turn (§2 ft)
3. Utilizes existing wells and facilities.
4. Less Expensive.
5. Production or injection.

Disadvantage

1. Small hole size.
2. Short length (300 ft).
3. No experience in oil sands.
4. Formation damage during drilling.
5. No liner completion.
6. No workover or re-entry.

7. Not suitable for deviated wells.

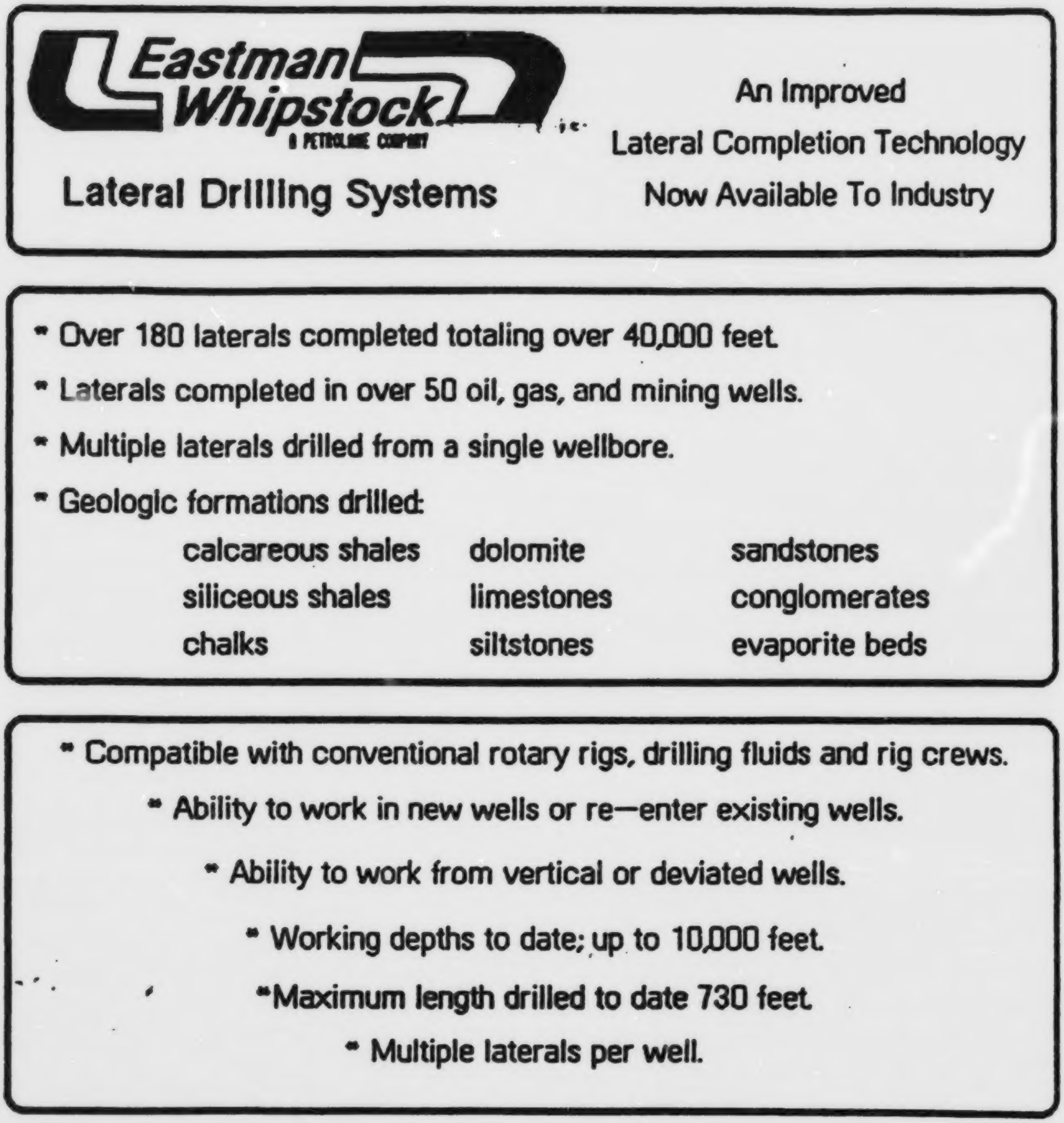
Texas Eastern Drainhole

Advantages
1. Multi-leg capability.
2. Short 90° turn (§35 ft).
3. Use existing wells and facilities.
4. Production or injection.
5. Liner completion.
6. Workover.
7. Less expensive.
8. Suitable for deviated wells.

Texas Eastern (cont.)

Disadvantages
1. Not tested in an unconsolidated sand.
2. Short length (700 ft).
3. One liner completion per vertical well.

Exhibit 1 contains copies of the literature from Bechtel and Texas Eastern, respectively, which is essentially a pictorial view of the two technologies.



Eastman Whipstock
A PETROLANE COMPANY

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An Improved
Lateral Completion Technology
Now Available To Industry

- Over 180 laterals completed totaling over 40,000 feet.
- Laterals completed in over 50 oil, gas, and mining wells.
- Multiple laterals drilled from a single wellbore.
- Geologic formations drilled:

calcareous shales	dolomite	sandstones
siliceous shales	limestones	conglomerates
chalks	siltstones	evaporite beds

- Compatible with conventional rotary rigs, drilling fluids and rig crews.
- Ability to work in new wells or re—enter existing wells.
- Ability to work from vertical or deviated wells.
- Working depths to date; up to 10,000 feet.
- Maximum length drilled to date 730 feet.
- Multiple laterals per well.

COVER PAGE OF EASTMAN WHIPSTOCK (NOW TEXAS EASTERN) LITERATURE IN EXHIBIT 1.

APPLICATION OF HORIZONTAL WELLS TO OIL SANDS AND HEAVY OIL FORMATIONS

Introduction

Many field tests of horizontal wells to oil/tar sand and heavy oil formations have been reported. Most of these were small scale operations, involving a few wells. In the following, we shall discuss the highlights of only the more significant field tests. Numerous Canadian and U.S. patents deal with oil recovery concepts utilizing horizontal wells in oil sands. These are considered briefly in the final section of this chapter. Very few of the ideas advanced in these patents are practical, however, it is instructive to ponder these flights of imagination.

Field Tests

Table 1, taken from Joshi (1986) (35) lists the horizontal wells drilled in various oilfields. It is seen that 26 field trials have been reported, with literally hundreds of wells drilled. Table 2 is more significant, since it lists the active horizontal well field tests. Four tests are still active; in oil sands, Esso's two horizontal wells and the Yarega wells in the U.S.S.R. are the only ones relevant to this study. However, the lack of activity in the horizontal well technology is a temporary situation attributable to the current (1986) low oil prices, and is not to be taken as a reflection of shortcomings of horizontal wells. AOSTRA's Underground Test Facility (UTF) is proceeding on schedule, and should provide a wealth of information on horizontal and inclined wells.

Esso's Horizontal Well in Cold Lake

Esso's first horizontal well, 300 m in length, was mentioned in the previous chapter. This well has been producing since 1978. Very little is known about it in the published literature. Mainland and Lo (1983) (36) reported that the well produced over 16000 m3 of oil from 1978 to 1982. If one allows for the additional time for the drilling of the horizontal well, the average production rate comes to about 12 m3/day, which is an improvement over the average rate of 8 m3/day for a vertical well under cyclic steam stimulation, for a 1.7 ha (4 acre) spacing. This is based upon eight cycles over an eight-year period. The original concept of a horizontal well to be used as both an injector and producer was modified to the role of the well basically as a producer, with vertical wells drilled for steam injection.

Esso's second horizontal well is much longer, 1000 m, with intersecting vertical wells spaced at 500 m. Based upon the scant information available, a heated annulus steam process was

TABLE 1 HORIZONTAL WELL - STEAM FIELD PROJECTS
(Joshi (35)

Company & Year	Location	Reference	Horizontal Wells		Steam Process	Cum. Oil Production (bbls)	SOR	Status & Comments
			Number	Length (ft)				
Yerga	USSR	Butler, 1984	Many	300 max	--	--	--	Active/Mine Assist.
Signal Oil Co. (1965-66)	Sunny Side, Carbon County Utah	Marchant, 1984 Combs, 1967	3	370 ft. but 50 ft. open to pay zone	cyclic & drive	566	23	Inactive, 9°-10° API oil, drilled from a outcrop side
Petro-Canada & other companies MAISP-I (1978)	Fort McMurry, Alberta, Canada	Towson, 1984	1 2	330 met 120	cyclic & drive	--	16	Inactive, ~10°API, drilled from a outcrop side
Hopco (1979)	Kern County, California	Rintoul, 1982 O & G J., 1982	4 4	430 730	cyclic	19,907	--	Inactive, 13° API oil, drilled from a shaft
Esso - I (1979) Esso - II (1985)	Cold Lake, Alberta, Canada	Bezair & Markiw, 1979 Baldwin et al., 1983 MacDonald, 1985	1 1	1000 3200	cyclic steam & steam assisted gravity drainage	--	--	Active, ~10°API Active, ~10°API
Texaco (1979)	Fort McMurray Alberta, Canada	Loxam, 1982 Pugh, 1982 Oil Week, 1986	3	1000	cyclic & drive	--	--	Inactive, ~10°API drilled from the surface
(1986)	California	--	1	--	cyclic	--	--	Active, 13°API oil
Petrobrass (1985)	Fazenda Belam Field, Brazil	EOR Week, 1985	1	544	(?)	75 BOPD	--	14°API oil
Planned Project								
MAISP (1985-87)	Athabasca Tar Sands, Alberta, Canada	Best et al., 1985	356	--	--	--	--	Mine/shaft project, 10°API oil

TABLE 1 (cont'd)

Horizontal Wells Drilled

Year	Company	Field	No. of Wells	Depth (ft.)	Reservoir Contact Length (ft)	(Horizontal/ Vertical)cost	Comments
1981-84	ARCO	Empire Abo Unit, New Mexico	8	6200	300-400	$250,000/well	Drilled through existing vertical well
1982-84	ARCO	Southeast Douglas Garfield County, OK	1	6500	300-400	" "	Drilled from the existing low producer vertical well into fractured Mississippi limestone.
1985	Esso, Canada	Cold Lake, Alberta Canada	1	1558	3330	--	Cyclic steam stimulation
1985	Petrobras	Fazenda Belam Field	1	1000	554	--	Produces five times better than the surrounding vertical wells.
1985	Sohio	McMullen Co., Texas	1	10300	1908	--	Long horizontal well
1985	Sohio	Glassock Co., Texas	1	--	295	--	Short drainhole
1985	Sohio	Prudhoe Bay, Alaska	1	8989	1400	2	Three fold increase in oil production rates over conventional well.
1986	Sohio	Prudhoe Bay, Alaska	1	9000	--	1.4	Three fold increase in oil production rates over conventional well

Table 2 **Horizontal Wells Drilled**

Year	Company	Field	No. of Wells	Depth (ft.)	Reservoir Contact Length (ft)	(Horizontal/ Vertical)cost	Comments
1937	--	Yarega, USSR	many	--	1000 max	--	Mine assisted steam
1941	Leo Ranney, et al.	McConnesville, Ohio	6	--	1000	--	Drilled through a tunnel
1942	--	Franklin Heavy Field, Venango County, PA	4 4	388 388	1000 600	Very Expensive --	Drilled through a tunnel
1942(?)	--	Midway Sunset, San Joaquin Valley, CA	2	1100	70	--	Drilled through existing vertical well using downhole motor and flexible drill pipe
1946	--	Round Mountain Field, Kern County, CA	9	1650	56	--	" " " "
1952	--	San Joaquin Valley, CA (Midway Sunset)	1	1200 3700	50 50	--	Six drain holes from a well Six drain holes from a well
1952	Venezuelan Oil Concessions, Ltd.	La Paz Field, Western Venezuela	?	10,000	50-100(?)	--	Drilled to reduce gas coning
1952	Long Beach Oil Development Co.	Los Angeles Basin Area (Wilmington Field)	8	3500 to 4800	50	--	In each well 6 to 8 drainholes were drilled. In some wells several drainholes were drilled at depth to reach many zones
1957	--	USSR	1	1000	300	--	Production Well
1967	--	China	1	3600	1600	--	Produced 5 to 10 times more fluid than a vertical well but collapsed in 7 days.

attempted at first, circulating hot water in the annulus to create conductivity in the surrounding oil sand. This concept was developed in a patent by Porter (1984) (37). Apparently, even after heating in this manner for six months, steam injection pressure was still 9 MPa.

On the basis of the very little information available, it can be said that horizontal wells in Cold Lake have a role to play as producers with oil inflow by gravity drainage, enhanced by steam injection from the vertical well. The productivity of a horizontal well is significantly higher than that of a vertical well; it is not known whether it is high enough to justify the additional drilling and operating costs of a horizontal well. Many such wells need to be drilled before average performance could be ascertained.

Surmont Project, South Athabasca

In Septemeber 1979, Gulf Canada Resources and AOSTRA entered into an agreement to determine the technical, economic and environmental feasibility of recovering bitumen from oil sands using a system of horizontal wells and a steam recovery project. Details are given by Horkoff (1982) (38). Two methods of access to the bitumen bearing formation were to be considered: horizontal wells drilled from the surface, and wells drilled from tunnels located above, within, or below the pay zone. The horizontal well system was considered to be more cost-effective. The project site was in the southern part of the Athabasca deposit. The target was the McMurray formation at a depth of 275 m, with thickness ranging from 25 to 43 m. The project was terminated in 1984 for unknown reasons.

Yarega Mine, U.S.S.R.

The Yarega field in the U.S.S.R. is located near Ukhta, 1300 km northeast of Moscow. The field was discovered in 1932, and began conventional production the following year. Reservoir and performance data on the field are shown in Table 3. Conventional development was only able to recover about 2% of the oil in place. A mine-assisted oil production scheme was initiated in 1937, which raised the recovery to a level of 6 to 10% of the oil in place by gravity drainage. Steam stimulation was added to the mining scheme beginning in 1968, and resulted in significant improvement in recovery to levels of 40 to 50% over a period of four years.

Three basic Yarega systems have been developed (39-42). In the Ukhta system, tunnels and channels are mined into the cap rock and a dense network of straight shallow production wells 12 cm in diameter are drilled into the producing formation below (Fig. 5). The wells are spaced at 15 to 20 m intervals. Steam injection wells are drilled to each heat an area of 200 to 300 m2, with steam pressures of 300 to 400 kPa. The second system involves main access and ventilation tunnels in the cap rock, with inclined openings driven downward to the oil reservoir, as shown

TABLE 3

YAREGA FIELD U.S.S.R

RESERVOIR CHARACTERISTICS

formation type	sandstone
thickness, m	70
depth, m	180-200
initial pressure, psi	220
initial temperature, °F	43
initial oil saturation wt%	7
porosity, %	24
permeability, darcies	3.17
oil specific gravity	0.95
oil viscosity, cp	11,000 to 15,000

FIELD PERFORMANCE

total crude production	2190 bbl/d
steam	3.5 tons/tons of crude
recovery with mining and steam	40-50% of oil in place
recovery with mining	6-10% of oil in place
conventional recovery	2% of oil in place

OIL VISCOSITY[37]

Temp, °C	Viscosity, cp
5	16 080
10	10 060
15	5 374
20	3 420
25	2 175
30	1 380
40	633
100	29.5

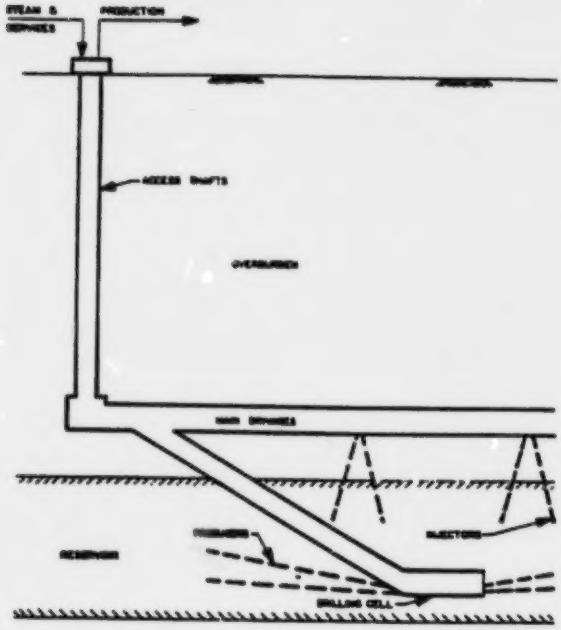

STEAM &
SERVICES
PRODUCTION
ACCESS SHAFTS
OVERBURDEN
MAIN DRIVAGES
PRODUCERS
INJECTORS
RESERVOIR
DRILLING CELL

Fig. 5 - Yarega mine schematic (After Haston).

in Fig. 5. Chambers are then cut in these inclined openings and low angle wells up to 200 m in length are drilled radially from these chambers. The ends of the production wells are spaced at no more than 15 m apart. In the third system, main access and ventilation tunnels are bored in the deposits lying below the reservoir. Vertical and slanted wells are drilled from chambers spaced at equal intervals along the tunnels. The crude oil moves into the tunnels by gravity drainage. Produced fluids are collected through an open drain system, rough skimming and desanding are done underground, and the production is then pumped to the surface for final treatment.

The tunnels which are used in the Yarega processes are located mostly in a competent tuffite formation located directly above the producing horizon. The oil reservoir is a competent sandstone which does not require support for walls or roof of tunnels. The introduction of steam into the reservoir must be done carefully so as to avoid steam breakthrough into the excavations. An efficient ventilation system is required to remove hydrocarbon vapours emanating from the heated oil, and to keep underground temperatures in a tolerable range. The oil flows in an open drainage network. High water-oil ratios, emulsion breaking problems, and sand-plugging of production wells have been experienced.

Baku Area Fields, U.S.S.R.

Plans were made in 1976 to apply technology developed in the Yarega field to the 100-year old Balakhany field, northeast of Baku in Azerbaidjan (37). This field lies at a depth of about 400 m. The Russians have also considered using undersea mining for old offshore fields in the Baku area, and possibly to develop new fields in the Caspian sea.

Two possible techniques are envisaged for undersea oil mining. The first is applicable to near shore fields and involves sinking two shafts from an on-shore location to a level of 60 to 80 m below the sea bottom. Two horizontal tunnels are then drilled to run the full length of the underlying oilfield parallel to its main axis. The second method is applicable to oilfields further from shore in water no deeper than 100 to 150 m. A vertical structure of reinforced concrete is prefabricated on shore, which is tall enough to reach and rest on the sea bottom. Following installation of this structure, main access and ventilation shafts are drilled to a depth of 60 to 80 m below the sea floor, and horizontal tunnels bored as in the first case. Undersea mines with access shafts located on shore would be immune to weather conditions, and would involve reduced risk of sea pollution. From the point of view of safety, the Soviets currently consider working levels to be limited to 750 m for undersea mines.

In 1979, it was reported that belated preparations were underway to drill shafts for the first underground mine in Azerbaidjan. The plan was for two shafts to be sunk to a depth of 340 m in the

Balakhany field. Originally, plans had called for opening of the first mine in 1978. The shafts and tunnels for this project will penetrate sands and shales and will be susceptible to cave-ins. No mention was made of employing steam injection. It can be assumed that slanted wells and steam would be employed to make use of the Yarega experience. Drilling of the first shaft began in late 1980, and start-up was scheduled for 1982 or 1983.

The "Hot Plate" Project, California

The so-called "Hot Plate" heavy oil recovery process (HOP), was originally conceived by Cornell Oil Company in California, discussed in detail by Wimer (1982) (43), Rintoul (1982) (29), and others (44). The process was successfully tested in the Kern River field, Calif. The concept involves heating the heavy oil reservoir initially at the base of the interval, by injecting steam into a system of horizontal wells radiating from a vertical well, like spokes on a wheel. A large diameter vertical borehole terminating in a below-ground cavern at the base of the pay zone is first drilled (see Fig. 6). Horizontal wells extending radially from the cavern are drilled into the oil sand to serve as steam injectors and heavy oil/water producers. Steam is generated at the surface using conventional equipment, and all production treatment facilities are also at the surface.

In the actual field test - now defunct - eight horizontal wells were employed, at a depth of 150 m, radiating from a 1.5 m diameter shaft. The wells were cyclically steam stimulated, producing 1160, 1000, and 1000 m3 of oil for the months of January to March, 1985. The project was shut down in April 1985. The oil production rate increased from 15 to 90 m3/day in this period. However, this was about one-half of the expected production. Well completion seems to have been a problem in this test.

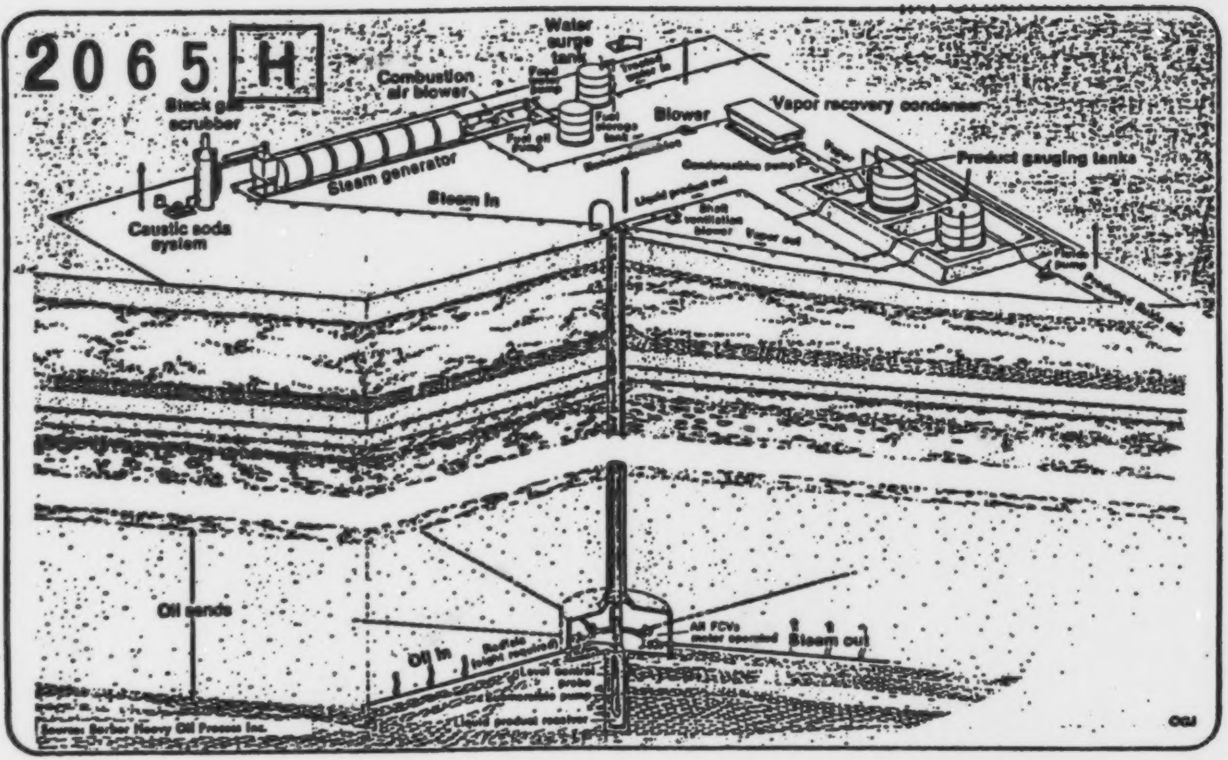
Other Horizontal Well Field Tests

A number of other horizontal well field tests have been reported. One of these, consisting of a single well was initiated in 1986 in a 13 deg API oil formation, in California. The test is in progress; no other information is available at this time.

A 165 m long well was drilled in Brazil's Fazenda Belem field, in a 9 m thick pay zone, with production of 85 m3/day, compared to the vertical production rate of one-fifth as much. No steam injection was involved in this case.

Hoffman and Ruehl (1953) (45) described oil mining operations in Germany, in several fields, containing oils of viscosities ranging from 20 to 5000 mPa.s. A system of tunnels and shafts was employed with laterals to increase drainage. The operation was said to be successful.

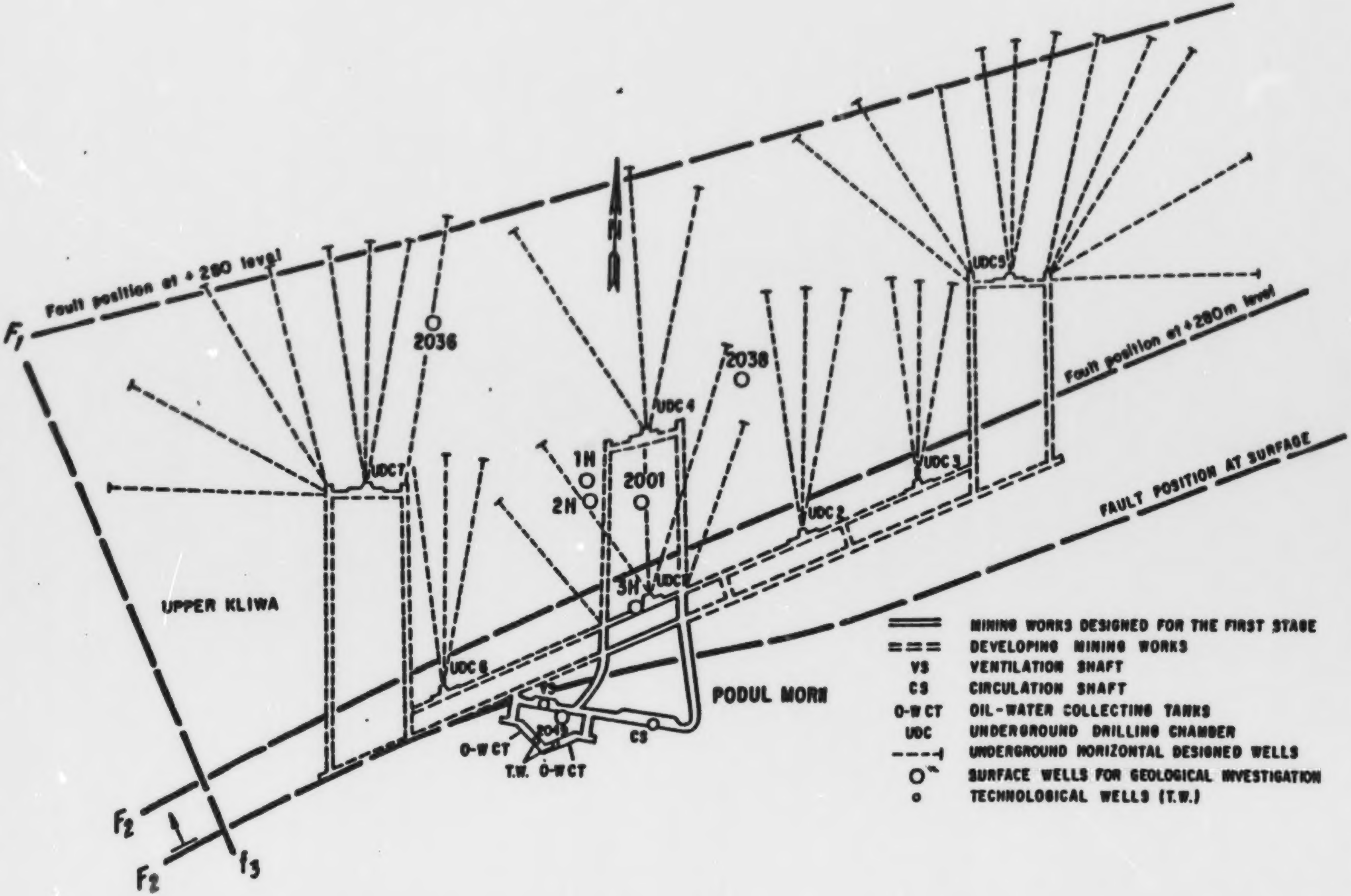
Aldea and Sandru (1985) (46) have described several oil mining operations in Romania, employing horizontal wells. Figure 7



2065 H
Water surge tank
Combustion air blower
Stack gas scrubber
Steam generator
Fuel storage tank
Fuel oil pump
Blower
Vapor recovery condenser
Product gauging tanks
Condensable pump
Caustic soda system
Steam in
Liquid product out
Shaft ventilation blower
Vapor out
Oil sands
Oil in
All FCVs motor operated
Steam out
Level control probe
Submersible pump
Liquid product receiver
OGJ

Source: Barber Heavy Oil Process Inc.

Fig. 6 - Schematic of the HOP method in the Kern field, California.



Fault position at +280 level
Fault position at +280m level
FAULT POSITION AT SURFACE
F1
F2
F2
f3
UPPER KLIWA
PODUL MORII
UDC 7
UDC 6
UDC 4
UDC 2
UDC 3
UDC 5
2036
2038
2001
1H
2H
3H
VS
CS
O-WCT
O-WCT
T.W.
MINING WORKS DESIGNED FOR THE FIRST STAGE
DEVELOPING MINING WORKS
VS VENTILATION SHAFT
CS CIRCULATION SHAFT
O-WCT OIL-WATER COLLECTING TANKS
UDC UNDERGROUND DRILLING CHAMBER
UNDERGROUND HORIZONTAL DESIGNED WELLS
SURFACE WELLS FOR GEOLOGICAL INVESTIGATION
TECHNOLOGICAL WELLS (T.W.)

Fig. 7 - Location of the mining shafts in the Runcu-Bustenari field, Romania.

shows a plan of the Runcu Bustenari mine, 400-600 m deep. At present there are 52 horizontal wells, which should produce 35% of the 5.6 mPa.s oil. Other mines produce more viscous oils (10 to 500 mPa.s). The total oil production during 1981-84 was 40 m3/day.

The four wells drilled by Elf Aquitaine in Europe have been described in numerous publications, a few of which were mentioned in the Chapter on drilling. In these, and other (47-49) publications, it is shown that horizontal wells are not only economically feasible, they can also provide solutions to special problems such as water coning in a bottom water situation. Of the four wells drilled, only one was in a heavy oil formation (11 deg API, 300 mPa.s). This well was drilled into an offshore karst formation, with a total thickness of 100 m, the bottom 30 m being water. The oil production rates for this well and of a comparable vertical well are shown in Table 7. The horizontal well produced three times as much oil as the vertical well, and took two to three times as long to drill. It was concluded that horizontal wells are desirable in tight reservoirs, in thin beds, in soft formations, such as chalk, in formations susceptible to vertical fracture formation, and in situations where bottom water coning may occur.

In 1979, Conoco developed an oil mine in the North Tisdale field, in Wyoming (Dobson and Seelye, 1980,1982 (50,51)). The field is 90 m deep, and produces a 28 deg API, 19 mPa.s oil from a thin (3.6 m) sandstone. Production is primarily by gravity flow. A 300 m adit was mined into the side of the Tisdale Mountain, and from the end of the adit, six horizontal wells, totalling 1830 m length were drilled. In 1981, a second production set was developed by sinking a 72 m vertical shaft 4.3 m in diameter, and again drilling six radiating horizontal wells. The initial total production rate from the adit and shaft was 30 m3/day, which quickly declined to about 2 m3/day. In 1984, New Tech Oil Co. took over the operation, opening nine drilling stations, and drilled nearly 5000 m of hole. The oil production rate is expected to reach 150 m3/day by the end of 1986.

Sherrard (1986) (52) has described the application of horizontal wells in the Prudhoe Bay field, Alaska. Depth is 2600-2700m, and the objective was to test three horizontal wells with lengths on the order of 1500 m. Two of the wells were successfully drilled and completed, at a cost of $282 to $462 per ft, as compared to $233 for a vertical well. The wells are producing at rates three to four times those for a vertical well. Numerical simulations showed incremental oil productions in the range of one million m3.

Other mine-assisted oil recovery projects have been reviewed by Sinor (1985) (53).

AOSTRA's Underground Test Facility (UTF)

An innovative development in the technology of mining and horizontal well method applications to oil sands is AOSTRA's Underground Test Facility. The first phase of MAISP (Mine Assisted In Situ Project), the forerunner of UTF, involved drilling and completion of horizontal wells, as outlined by Quinn and Duncan (1979) (54). Petro-Canada, acting as operator for a consortium of companies, completed a three-well horizontal drilling test at an outcrop site in the Athabasca river valley at Mildred Lake, north of Fort McMurray. The wells were successfully completed and stimulated. The overall objective was to increase confidence in proceeding to an underground test and to obtain design data. The steam injection phase of the project was to evaluate 1)effects of thermal expansion of casing, 2) movement of the wellbore during production, 3)the success of the high temperature cement, 4)the amount of sanding, 5)time required for each steam stimulation cycle, 6)the extent of heating, 7)thermal characteristics of oil sand, and 8)the injection and production rates and volumes. Bitumen production is said to have exceeded expectations.

The UTF project has been described by a number of authors. Towson (1984) (55,56) reviewed the MAISP, noted above, and described the proposed shaft and tunnel mine scheme. Haston (1985) (57) has discussed the mining aspects of UTF, Patterson (1985) (58) describes the tunnelling methods, and Bohme and Strickland (1985) (59) deal with the question of drilling wells from underground. Carrigy and Stephenson (1985) (60) the progress made in the UTF development to 1985, together with a review of objectives and need for such a facility. Best, Cordell, and Haston (1985) (61) and Luhning (1986) (62) give the most recent reports on the project. A brief description follows.

The UTF site is located on about 9 ha some 60 km northwest of Fort McMurray, delineated by 31 wells. The target is the 30 m thick McMurray formation, overlying limestone formations. The latter was chosen for underground tunnels. Figure 8 shows a schematic of the underground facility. Two main shafts have been sunk through the McMurray formation to the underlying Devonian limestone at a depth of 213 m, using the blind boring method (58). One of the shafts is for production, while the other one is for servicing and emergency use. The shafts have been successfully completed, and the underground tunnel complex is proceeding on schedule. From the pit bottom complex, a system of production tunnels will be driven through the limestone to provide access for drilling horizontal wells up into the McMurray formation. One tunnel, 20 m below the base of the oil sand, will be used for the access and main ventilation purposes. The other, 8 m below the base of the oil sands, will be used for drilling the wells.

A novel drilling system has been developed for drilling the horizontal wells, and placing them near the base of the oil sand, in a closely spaced configuration. Drilling from a tunnel in the limestone implies that the hole be drilled upslope and deviated several metres into the oil sand, and then drilled horizontally through the oil sands formation. A special slant rig has been

Table 4

ROSPO MARE PILOT PRODUCTION DATA

WELL	MAXIMUM RATE	PRESENT RATE	CUMULATIVE OIL
RSM4 VERTICAL	200 m^3/d (1,250 bbl/D)	100 m^3/d (625 bbl/D)	70 000 m^3 435,000 bbl
RSM5 SLANTED	48 m^3/d (300 bbl/D)	0 m^3/d (0 bbl/D)	13 000 m^3 81,000 bbl
RSM6 HORIZONTAL	570 m^3/d (3,600 bbl/D)	320 m^3/d (2,000 bbl/D)	203 000 m^3 1,270,000 bbl

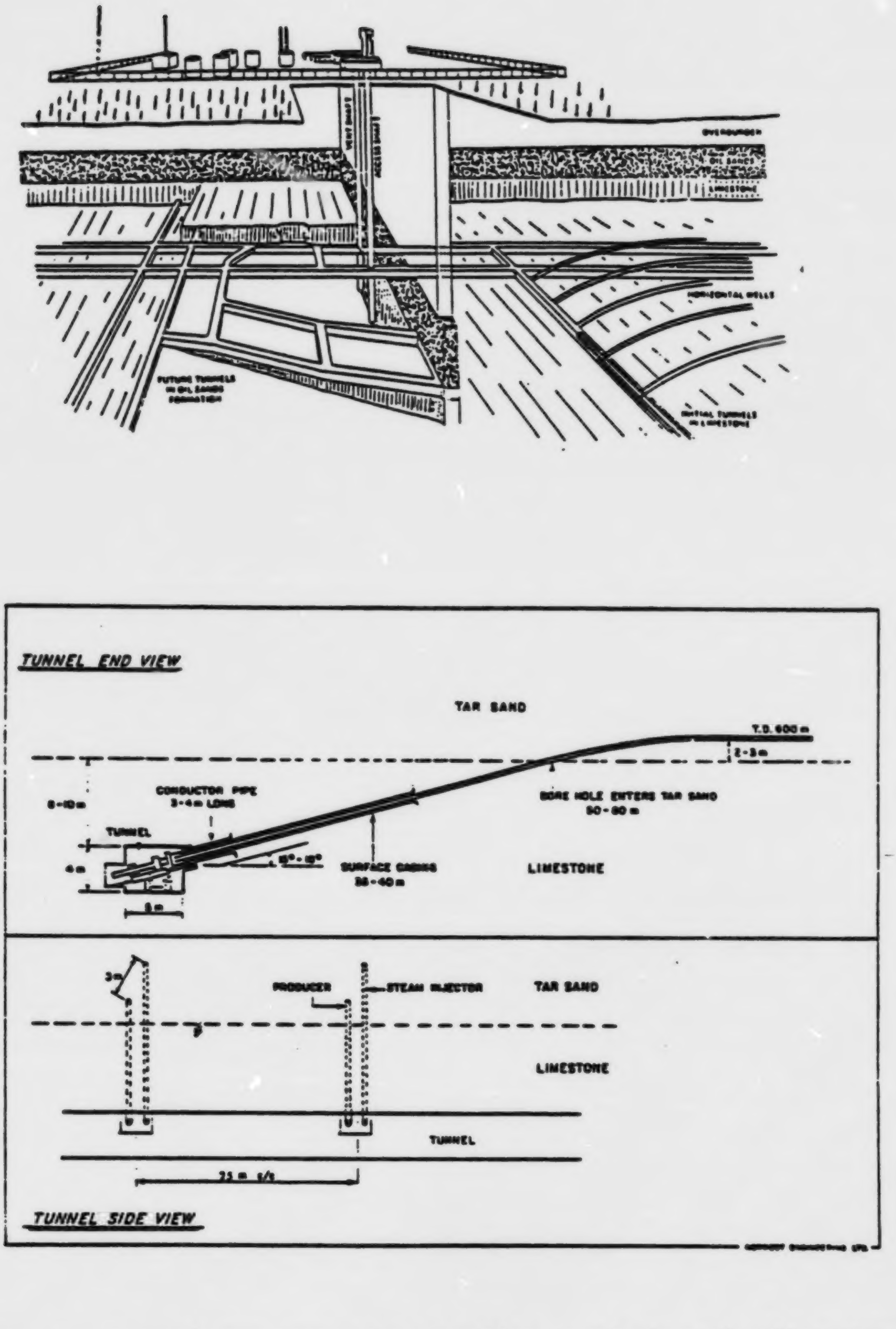

OVERBURDEN
OIL SANDS
LIMESTONE
HORIZONTAL WELLS
FUTURE TUNNELS IN OIL SANDS FORMATION
INITIAL TUNNELS IN LIMESTONE
TUNNEL END VIEW
TAR SAND
T.D. 600 m
2-3 m
8-10 m
CONDUCTOR PIPE 3-4 m LONG
BORE HOLE ENTERS TAR SAND 50-60 m
TUNNEL
4 m
15°-18°
SURFACE CASING 36-40 m
LIMESTONE
5 m
3 m
PRODUCER
STEAM INJECTOR
TAR SAND
LIMESTONE
TUNNEL
25 m c/c
TUNNEL SIDE VIEW

Fig. 8 - AOSTRA's Underground Test Facility, and horizontal well system.

designed and built for this purpose. Extensive numerical simulation studies, discussed in Chapter 9 have established the superior performance of the wells drilled horizontally from underground.

Oil/Bitumen Production Processes Based Upon Patents

Many heavy oil/bitumen recovery methods have been patented in Canada and the U.S.A. Some of these offer interesting concepts which may become feasible one day. However, by and large, most ideas are impractical. Appendix A provides a summary of the patents, descriptions of which could be obtained. Notable among these are the patents on the heated annulus steam drive (Porter, US 1984), and the four patents on horizontal wells (Towson, Canada 1984). Copies of the patents are contained in Exhibit 2 in chronological order, starting with 1986.

LABORATORY STUDIES OF HORIZONTAL WELLS

Introduction

Very few laboratory studies of horizontal wells have been reported. The earliest one is that due to Huygen and Black (1982) (63), which shows that interest in horizontal well technology is a recent phenomenon. Other notable contributions are those due to Coates (1984) (64), Toma, Redford, and Livesey (1984) (65), Griffin and Trofimenkoff (1984) (66), Joshi (1984) (67), Joshi and Threlkeld (1985) (68), and Joshi (1986) (69). The models used were unscaled in all cases, except the one used by Huygen and Black. A brief description of the experimental methods used follows.

Models Used

Huygen and Black (1982) (63) used a high pressure scaled model for steam injection experiments, with different horizontal well placements. The scaling was chosen to model Gulf's Surmont, Athabasca, field test. The model dimensions were 54 cm x 54 cm x 15.3 cm. It was fabricated from thin metal, and placed inside a high pressure shell operated at 3 MPa. Several strategies were used for linking the wells, viz. with and without fractures, and using horizontal wells. A single horizontal well was found to be an efficient means for oil recovery at an acceptable oil-steam ratio. This experimental study reflects Gulf's previous experience with high pressure scaled models, and is the most sophisticated among the reported works. The reservoir was scaled using the steamflood criteria, but the horizontal well was not scaled.

Coates (64) used a triaxially loaded pressure vessel with inside dimensions of 150 cm length and 40 cm diameter. A diagram of the apparatus is shown in Fig. 10. High pressure nitrogen was used to simulate the overburden pressure. Two horizontal well configurations were used, as shown. It is clear that the model, while large enough to minimize errors, is unscaled, and could only provide a qualitative idea of the process under consideration. Various types of steam and solvent injection schemes were used to test the two types of horizontal wells.

Toma et al (65) used a high pressure unscaled shell, inside which an oil sand pack was placed, with a horizontal well running through its centre. Figure 11 shows a sketch of the model, as well as the relevant dimensions of the horizontal well. Various types of cyclic steam stimulation runs were carried out. The results showed that bitumen recovery was a function of axial pressure drop in the well. Improvement was obtained when solvents and carbon dioxide were used as additives.

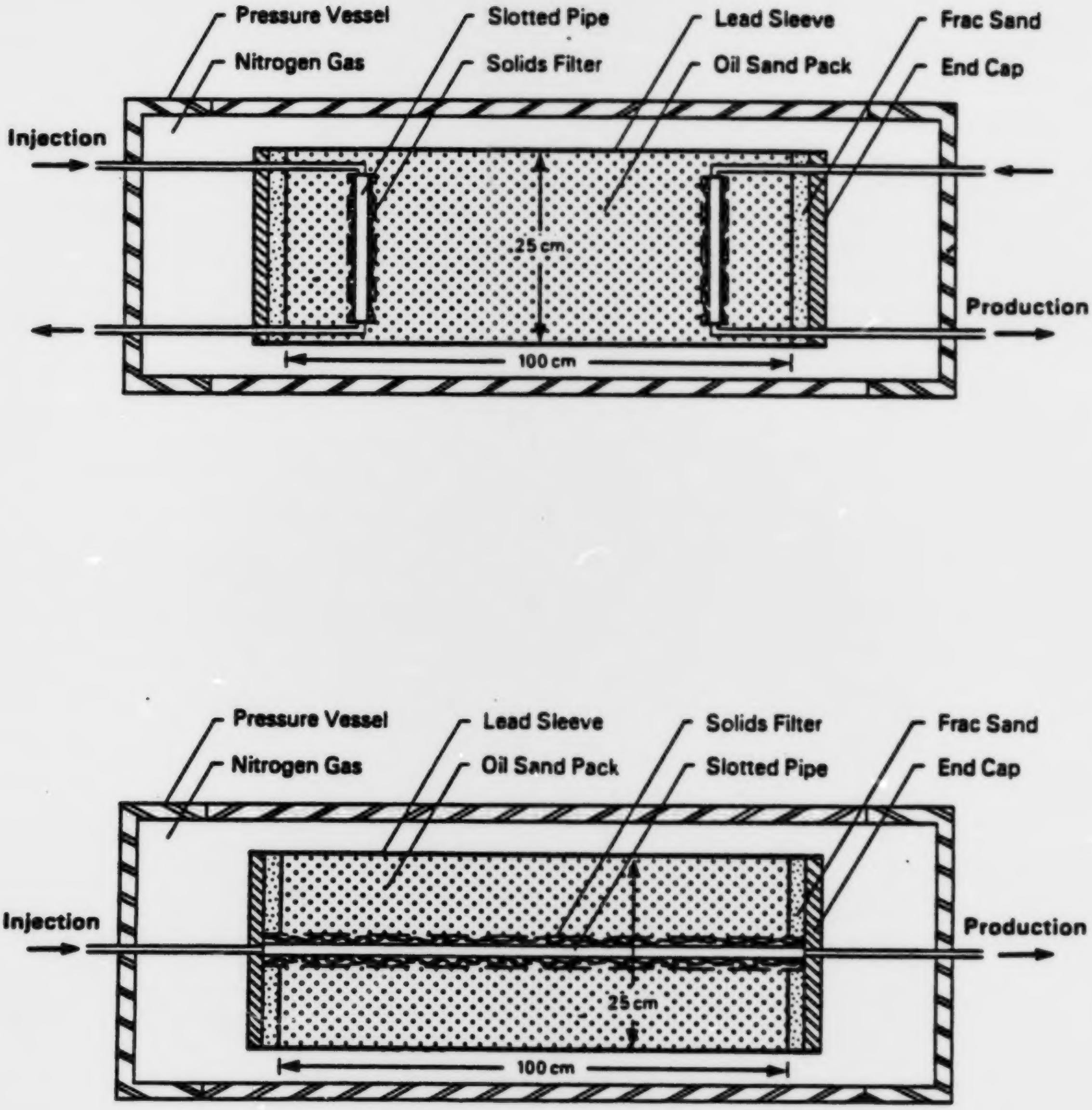

Pressure Vessel
Nitrogen Gas
Slotted Pipe
Solids Filter
Lead Sleeve
Oil Sand Pack
Frac Sand
End Cap
Injection
25 cm
Production
100 cm
Pressure Vessel
Nitrogen Gas
Lead Sleeve
Oil Sand Pack
Solids Filter
Slotted Pipe
Frac Sand
End Cap
Injection
Production
25 cm
100 cm

Fig. 10 - Coates's horizontal well simulation apparatus.

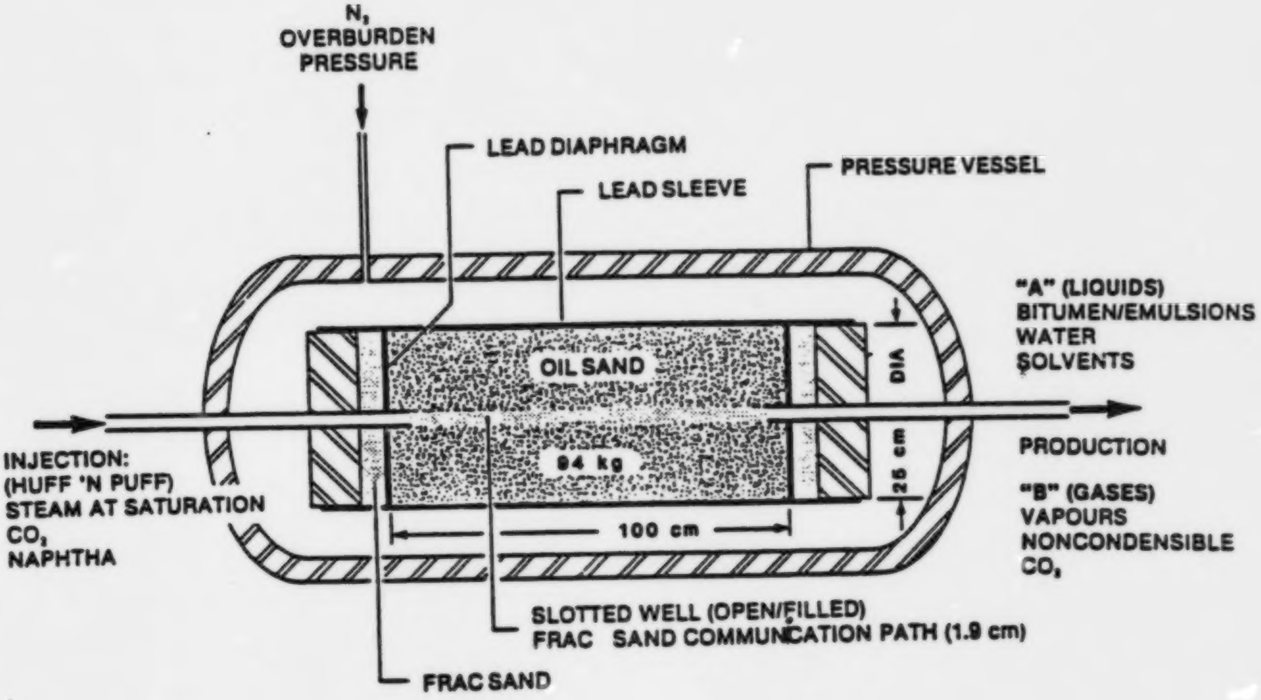
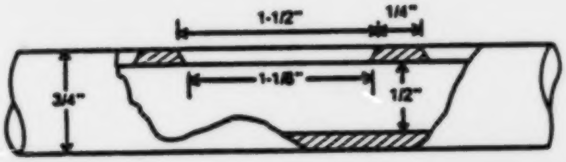

N₂
OVERBURDEN
PRESSURE
LEAD DIAPHRAGM
LEAD SLEEVE
PRESSURE VESSEL
"A" (LIQUIDS)
BITUMEN/EMULSIONS
WATER
SOLVENTS
OIL SAND
94 kg
DIA
25 cm
PRODUCTION
"B" (GASES)
VAPOURS
NONCONDENSIBLE
CO₂
INJECTION:
(HUFF 'N PUFF)
STEAM AT SATURATION
CO₂
NAPHTHA
100 cm
SLOTTED WELL (OPEN/FILLED)
FRAC SAND COMMUNICATION PATH (1.9 cm)
FRAC SAND

Figure 1 (Detail). Alternate well completion schemes

	Open area slot
A. Slotted well (19 mm OD)	
length/width (mm/mm)	%
31/0.51	4.0
31/0.51	0.9
31/0.81	6.0
31/1.27*	9.5
31/1.27**	9.5
B. Screens (25 mm OD)	
Width (mm)	
1.6	33
0.8	33
C. Frac sand communication path	
#/OD	
12/19	33

* Filled with frac sand #16

** External sand filter


1-1/2"
1/4"
3/4"
1-1/8"
1/2"

Slot width: 0.02"		Slots alternate
Line lateral area	0.0586 m²	4 rows 18 slots (31¼")
Line median area	0.06 m²	4 rows 17 slots (29¼")
Slotted open area	0.002 m² (1%)	

Fig. 11 - Toma et al's horizontal well simulation set-up.

Griffin and Trofimenkoff (66) and Joshi and Threlkeld (67,68,69) primarily studied steam-assisted gravity drive of heavy oil. Butler is currently conducting similar studies at the U. of Calgary. The models used by the above investigators are basically vertical parallel plate type, packed with glass beads, with steam injection at desired locations. Griffin and Trofimenkoff also used a high pressure model. They studied horizontal well steam chamber growth in both the low pressure (visual) model and in the high pressure model. Agreement with theory was only fair.

Joshi et al (67-69) used a light oil in most of their parallel plate model runs; bitumen was also used, with similar results. he model was 12 inches x 4 inches x 10 inches (30x10x25 cm) high, designed for operation with 15 psig (205 kPa gauge) steam. Figure 12 shows a schematic of the model and the well configurations used. The model results showed that steam-assisted gravity drainage produced oil three times faster than drainage under cold conditions.

Proctor and Farouq Ali have conducted a series of steamflood experiments in a low pressure scaled model, using horizontal wells, and combinations of horizontal and vertical wells. In some of the experiments, a bottom water layer was also simulated. In a second experimental study, flow in the vicinity of a horizontal well is simulated using a water-air mixture at the present time. Future work will employ high pressure steam models for these studies.

Observations

It is clear that very few laboratory studies have been conducted so far, and for the greater part they are of qualitative value only. The major deficiencies of the models reported are that they are unscaled, and provide a limited representation of flow in the vicinity of the horizontal wellbore. Pressure drop in a horizontal well is important, and is not correctly simulated in any of the laboratory models. What is needed is a scaled model, preferably high pressure, of a single horizontal well, where the well diameter is large enough to model gravity flow. Further, a series of displacement studies should be conducted using systems of horizontal and vertical wells to examine the effect of well positioning as well as the usual steamflood variables.

Future laboratory studies can be built upon the work of Huygen and Black, with modifications. For example, a scaled high pressure model could be designed, with precise scaling of the horizontal well.

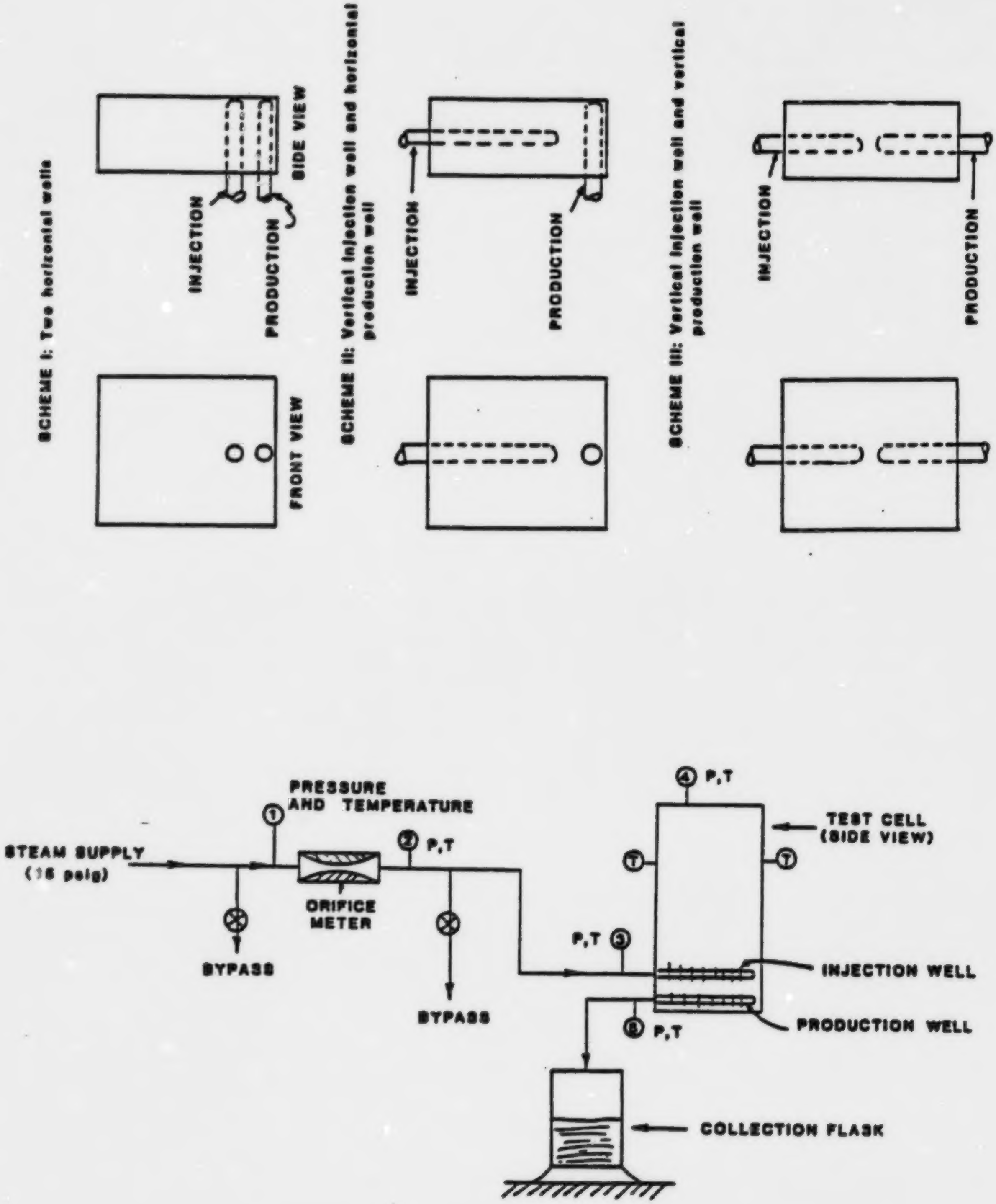

SCHEME I: Two horizontal wells
FRONT VIEW
SIDE VIEW
INJECTION
PRODUCTION
SCHEME II: Vertical injection well and horizontal production well
INJECTION
PRODUCTION
SCHEME III: Vertical injection well and vertical production well
INJECTION
PRODUCTION
STEAM SUPPLY
(15 psig)
BYPASS
①
PRESSURE AND TEMPERATURE
ORIFICE METER
② P,T
BYPASS
④ P,T
TEST CELL (SIDE VIEW)
Ⓣ
Ⓣ
P,T ③
INJECTION WELL
⑤ P,T
PRODUCTION WELL
COLLECTION FLASK

Fig. 12 - Joshi's horizontal well set-up, and well configurations used.

THEORETICAL STUDIES OF HORIZONTAL WELLS

Introduction

Horizontal wells have received a great deal of attention from a theoretical viewpoint. The reported studies fall into the categories of analytical treatments and numerical simulation. The latter is relatively easy, and with the proliferation of numerical simulators, is commanding the leading place. Analytical models, of necessity, must be simplified to be tractable. This makes them less useful. Nevertheless, analytical models are of value in generalizing limited data. In the following, we shall discuss the principal analytical models and numerical simulation studies.

Isothermal Gravity Drainage Models for Horizontal Wells

Among the published literature, the first treatment of horizontal and deviated well production rates is due to Borisov (1964) (70). A series of equations were derived. The basic premise was that a reservoir of finite thickness is penetrated over the entire thickness by "n" inclined wells, and that the vertical permeability is zero. The cases of a single horizontal well as well as clusters of such wells in the drainage hole fashion were also considered. The treatment is deficient in that two-dimensional flow, in particular, the action of gravity was not considered.

Giger and coworkers have published a series of papers giving equations for gravity drainage into horizontal wells. In a 1983 publication (71), he derived the critical flow rate formula for water coning in the case of a horizontal well. The analytical solution described the shape of the water cone developed by a horizontal well. Giger, Combe, and Reiss (1983) (72) discussed the benefits of horizontal wells, giving productivity index formulas for various situations. It was concluded that the productivity of a horizontal well would be 3 to 5 times that of a vertical well, and that the vertical sweep would be higher also. This was further expanded by Giger (1983) (73) in another paper, where a method was proposed for calculating the number of vertical wells that can be replaced by a horizontal well. Otherwise, the previously derived equations were employed.

Mervyn de Four (1985) (74) derived a set of useful equations for gravity drainage for several cases of a horizontal well. In particular, radial flow into a vertical well, radial flow into vertical fractures, linear gravity flow into a horizontal well, and flow into a vertically multifractured horizontal well were considered, and flow rate equations were derived for each case. This is a good paper for a great deal of information in one place.

In another series of papers by Giger and coworkers, additional formulas were given to calculate the flow rates for horizontal wells, and the critical production rate where water coning is a potential problem. Daviau, Mouronval, Crutchet, and Giger (1985) (75) discussed well test analysis for horizontal wells. Both infinite and finite reservoirs were considered, with constant pressure on the boundaries. The horizontal well was assumed to have infinte conductivity. It was shown that the early time pressure distribution is due to radial flow in a vertical plane; late time pressure behaviour is due to horizontal pseudoradial flow. This is a good paper, with a great deal of information in one place. Other papers dealing with pressure buildup in horizontal wells are the works of Goode and Thambynayagam (1986) (76) and Clonts and Ramey (1986) (77).

Karcher, Giger and Combe (1986) (78) gave formulas for horizontal well behaviour. The contents of this work are essentially the same as those of the previous works (72, 73). Another paper by Giger (1985) (79) again repeats this material. The latest paper by Giger (1986) (80) gives a two-dimensional analysis of a horizontal well with water coning. Critical time and rate equations are derived. Cone formation is considered in the contexts of gas cap drive, edge water drive, and bottom water drive. The theory developed offers a method for locating the best position for a horizontal well in the presence of bottom water.

Caperon (1986) (81) gives a series of formulas, similar to those of Giger, for calculating the critical production rate, in the presence of water cone formation, for both vertical and horizontal wells. It is shown that a critical cone came closer to the horizontal well than to a vertical well. Although horizontal wells allowed higher critical rates than vertical wells, the advantage lessened with an increase in anisotropy. Inclusion of this latter effect is the chief contribution of this work.

Non-Isothermal Gravity Drainage

Butler and coworkers have authored a number of papers describing gravity flow of a viscous oil with heating by steam. Butler, McNab and Lo (1979) (82) developed the concept of steam-assisted gravity drainage of oil for oil sands, where a "steam chamber" is created along the length of a horizontal well. Given this premise, an equation was derived, which gives the oil production rate, that is really invariant in time, although one could conceive of a time-variable head. This concept was further elaborated in subsequent papers, a good example being the 1981 work by the same authors (83). Although Butler et al's approach is simplified, it provides a useful means of estimating gravity drainage performace. As noted previously, Griffin and Trofimenkoff (66) used these equations and found limited agreement with their experimental data.

Numerical Simulation of Horizontal Wells

Numerical simulators of thermal processes provide a ready means of simulating horizontal wells. Many papers have dealt with the use of horizontal wells in steam-based recovery methods. Typically, a row of blocks (often 2m x 2m in cross-section) is assigned to represent the horizontal well. For the rest, the simulation is no different from a steam injection simulation, cyclic or continuous. Different well configurations and processes have been tried. A summary is provided in the following.

Steamflooding Rial (1984) (84), Jain and Khosla (1985) (85), Khosla and Cordell (1985) (86) Gussis (1985) (87), Huang and Hight (1986) (88) and Hseuh (1986) (89) discuss various simulation studies involving horizontal wells. The aforementioned procedure was employed in all cases. The results obtained in nearly all instances show very high productivities. Rial (84) simulated several cases of steam drive, for Kern River conditions (24 m thickness). The grid used and the results obtained for vertical and horizontal wells are shown in Figs. 13 and 14, respectively. It is clear that the vertical advance of the isotherms was much more uniform in the case of the horizontal well, but then, a whole row of blocks was taken to represent the horizontal well. It is interesting that the simulated performances of the horizontal (64% OIIP recovery) and vertical (51% OIIP recovery) wells were not too different.

Huang and Hight (88) modelled a number of horizontal and vertical well combinations. Of these, the highest recovery (72% OIIP) was obtained for the case of four horizontal production wells drilled radially from each corner of the pattern, plus one vertical well at the centre, and four additional vertical wells drilled at the centre of each quadrant, as shown in Fig. 15. Figure 16 shows the oil recovery curve for some of the injection-production well schemes tested.

The most useful study for the purpose of this report is that due to Khosla and Jain (85), in which a number of steam drive configurations were compared. These consisted of parallel horizontal wells, combination of a horizontal and a vertical well, and a surface deviated horizontal well with a heated parallel plane. The important aspect of this work is that it provides a realistic representation of the formation of interest, in the Athabasca area, using 10 layers of variable properties. The results reflect the effects of heterogeneities and saturation variations, and provide a useful comparative view.

Hseuh (89) recently reported the results of a simulation of the Heated Annulus Steam Drive (HASD) for the oil sands. It would be recalled that this process utilizes a horizontal, cased, unperforated pipe running between a vertical steam injection well and a production well. High temperature steam is circulated

Grid Block Parameters

	Layers			
	1 (top)	2	3	4 (bottom)
Thickness, ft.	12	9	20	30
Permeability, md.	5.500	5,500	2,000	1,400
Porosity, fraction	.34	.34	.34	.34
Depth, ft.	606	616	631	656
Initial Gas Phase Pressure, psia	55.5	60.0	66.5	78.0
Initial Water Phase Saturation	.28	.28	.30	.32
Initial Oil Phase Saturation	.72	.72	.70	.68
Pore Volume, bbls	409.7	307.3	785.2	1,024

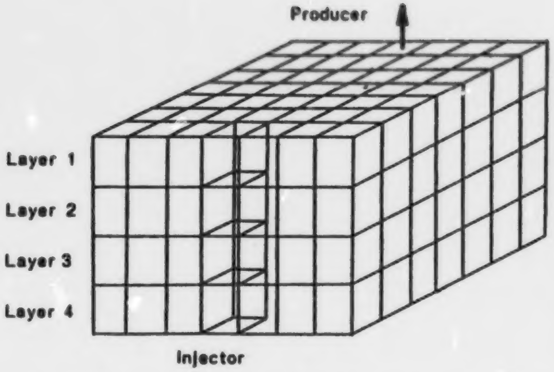

Producer
Layer 1
Layer 2
Layer 3
Layer 4
Injector

Fig. 1—Conventional vertical wellbore 7 X 7 X 4, 2.5-acre, one-fourth five-spot with 9 point difference.

$$\Delta x = \frac{\sqrt{\frac{1}{4}\times 2.5\times 43,560}}{7} = 23.57 \text{ ft}$$

141.42

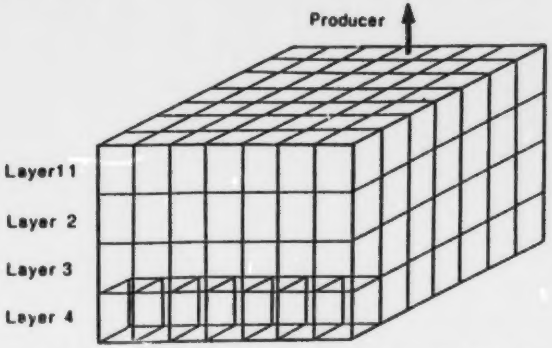

Producer
Layer1 1
Layer 2
Layer 3
Layer 4

Fig. 2—Horizontal wellbore model injection into bottom six grid blocks.

Fig. 13 - Details of the grid used in Rial's simulations of vertical and horizontal wells.

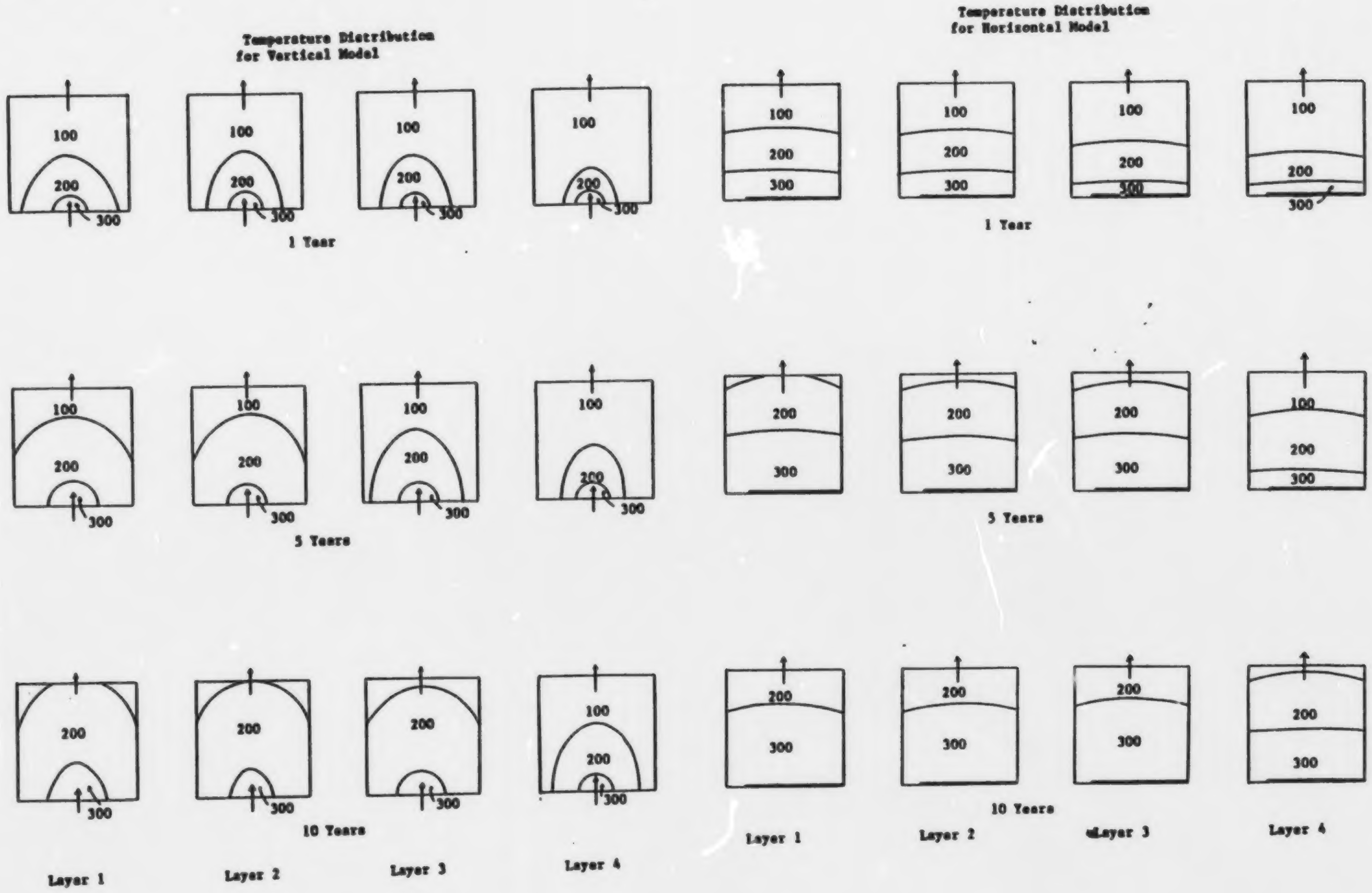
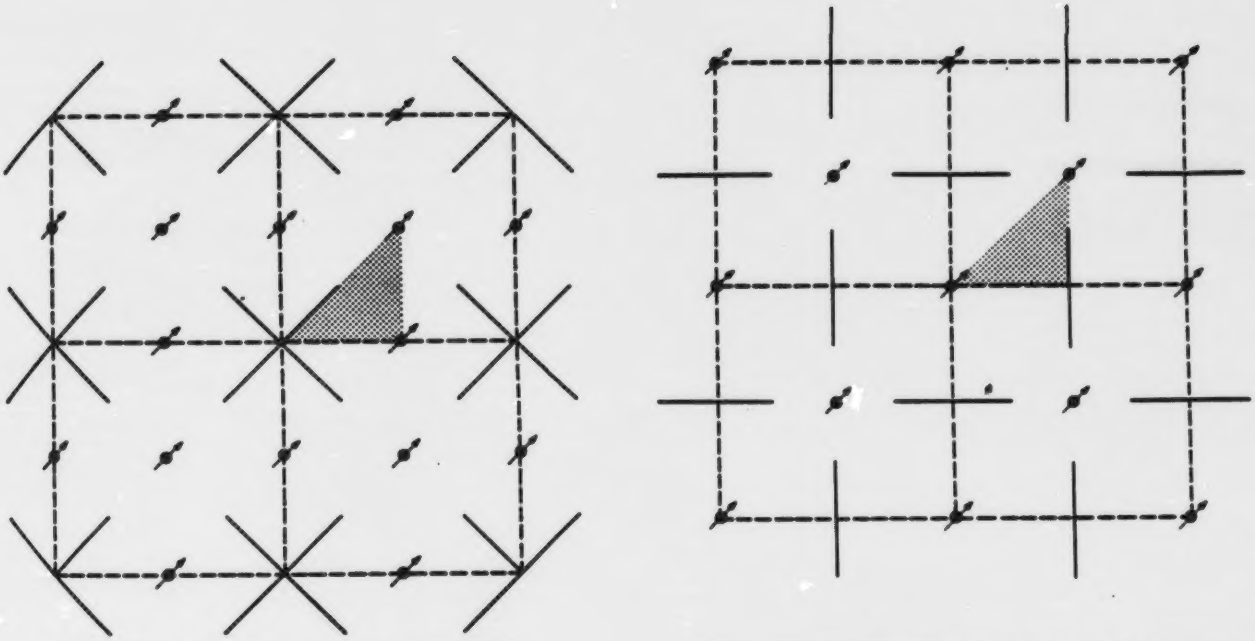
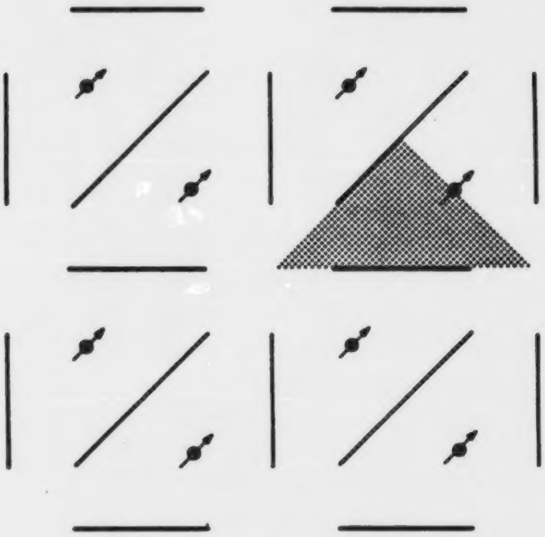

Temperature Distribution for Vertical Model
Temperature Distribution for Horizontal Model
100
200
300
1 Year
5 Years
10 Years
Layer 1
Layer 2
Layer 3
Layer 4

Fig. 14 - Calculated temperature distributions for vertical and horizontal wells in Rial's simulations.



SHADED AREA REPRESENTS 1/8 OF AN 18.5 ACRE (7.5ha) PATTERN

SHADED AREA REPRESENTS 1/8 OF AN 18.5 ACRE (7.5ha) PATTERN



SHADED AREA REPRESENTS 1/4 OF A 26 ACRE (10.5ha) PATTERN

Fig. 15 - Combinations of vertical and horizontal wells used in Huang's simulation studies.

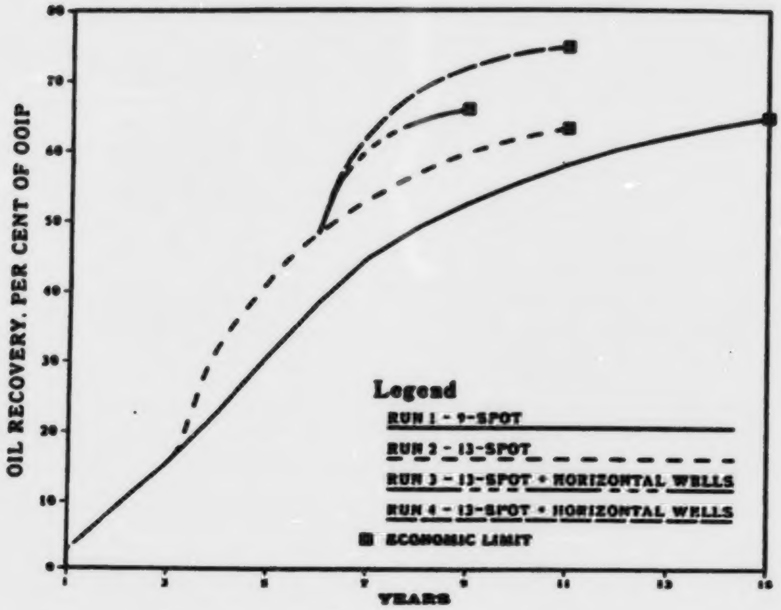


Fig. 16 - A comparison of horizontal and vertical well patterns, as reported by Huan, based upon numerical simulations.

through the pipe, heating the surrounding oil sand by conduction. Continuous steam injection at the vertical wells begins as soon as sufficient mobility has ben attained in the oil sand. The pipe acts as a permanently open communication path between the injector and the producer. The simulation results showed that the HASDrive process is feasible, and could produce as much as 70% of the in-place bitumen, using elongated well patterns to minimize the problem of early steam breakthrough.

Application of horizontal wells to miscible flooding was simulated recently by Chen and Olynyk (1985) (90).

Steam Assisted Gravity Drive It has been established by means of both field and simulation studies that steam-assisted gravity drive is the main production mechanism in horizontal wells used in a steam-based process. For example, this was one of the principal conclusions of the HASD simulation study discussed in the previous section. A number of simulation studies have examined this process in depth for a variety of configurations. Perhaps the definitive simulation study of this type is the work of Cordell, done at AOSTRA on an in-house basis. Selected graphs from this study are contained in the papers of Best et al (61) and Khosla and Cordell (1985) (86). Table 5, taken from the above reference, gives a comparative view of the different processes investigated. Unlike other numerical simulation studies on horizontal wells, none of these look particularly attractive, as the oil-steam ratios are low.

Other simulation studies reported include that of Gussis (1985) (87), in which the performance of a vertical well was compared with that of a horizontal well, for a 12 deg API oil and a 30 m thick formation. Several horizontal well patterns were used. The steam drive simulations, employing a horizontal injector and a horizontal producer, both located at the base of the formation, in a line drive configuration, were the most efficient. Location of the horizontal injector near the top of the formation resulted in excessive heat loss.

Observations

The above cited laboratory and simulation studies of horizontal wells are useful in a qualitative sense, especially if a good description of the subject reservoir is simulated. As noted previously, the laboratory studies are lacking in that the models were unscaled, and the representation of the horizontal well was inadequate. Much work needs to be done toward developing more realistic models, at least to the extent of correct scaling of the gravity drainage process.

As regards simulation studies, there are serious deficiencies. The representation of horizontal well is in effect the same as that of a vertical well with radial flow. No account is taken of the asymmetrical flow pattern around the well. This requires proper modelling of the streamlines around a horizontal well producing by gravity drainage. An example of effort in this direction is provided by the work of King and Ertekin (1984) (91), who compared vertical and horizontal drainage wells for degasification of coal seams.

Table 5

COMPARISON BETWEEN HORIZONTAL AND VERTICAL WELL PERFORMANCE
PER REPEATABLE PATTERN

PROCESS	OPERATING LIFE (Years)	CUMULATIVE STEAM INJECTED (m^3)	CUMULATIVE BITUMEN PRODUCED (m^3)	CUMULATIVE WATER PRODUCED (m^3)	CUMULATIVE OIL-STEAM RATIO (m^3/m^3)	CUMULATIVE DAY OIL RATE (m^3/d)
VERTICAL						
Cyclic Steam High Water Sat.	3	70,000	7,500	78,000	0.11	6.8
Cylic Steam High Bitumen Sat.	3	56,000	9,800	56,800	0.18	9.0
HORIZONTAL						
Steam Drive No Variations	3	267,000	61,400	308,000	0.23	56.1
Steam Drive Permeable Path	3	119,000	12,000	158,000	0.10	11.0
Steam Drive Double Spacing	3	275,000	38,500	380,000	0.14	35.2
Gravity Drainage High Water Sat.	4	346,000	56,800	343,700	0.16	38.9
Gravity Drainage High Bitumen Sat.	4	342,000	69,600	327,000	0.20	47.7

RECOMMENDATIONS AND DISCUSSION

The previous chapters summarized the present state of knowledge concerning the drilling, utilization, and performance prediction of horizontal wells. It was seen that the field experience with horizontal wells in oil/tar sands is limited, especially so in Canada. Laboratory experience is even more scant, with the few studies done in the last five years only. Numerical simulations have received greater attention, mainly on account of the availability of thermal models, but the representation of a horizontal well in such models is incorrect, leading to optimistic oil production forecasts. Nevertheless, there is little doubt that horizontal wells will play an important role in the development of oil sands, and as such, they merit attention.

Given the present state of knowledge, it is clear that there are numerous aspects of horizontal wells that require close examination. The following recommendations are offered only on the more important unknown areas, keeping in view the fact that cost-effectiveness of horizontal wells is an essential consideration.

Drilling

Horizontal well drilling techniques are developed to a point where it is feasible to drill such wells in the oil sands. Surveying, logging, and servicing of these wells are still in the development stage. In particular, locating a well laterally is subject to uncertainty. Of the two new drainhole drilling techniques, the Texas Eastern method is more promising for the oil sands, especially for the shallower formations of Athabasca.

Production

Horizontal wells have been shown to be more useful as producers than steam injectors. However, simulation studies - notwithstanding their limitations - and our laboratory studies show that they can be effective injectors also. It is recommended that the use of horizontal wells as injectors be investigated, particularly in regard to balanced steam injectivity over the length of the well, employing variable perforation density, variable diameter, etc.

In the cases of both drilling and production, it is suggested that attempts should be made to acquire other operator's data for horizontal wells in the oil sands. This includes Esso and Texaco, also Murphy, whose drainhole failed. It is also worthwhile to develop contacts with Horwell, in France, to see what they have to offer by way of well surveying and servicing. The Russians have apparently tried to sell, or sold, the Yarega data to Canadian operators and AOSTRA. Some information on the nature of this data might be useful for our purposes. Russian journals have published practically nothing technically useful on Yarega.

Field Testing

Field testing of horizontal wells is expensive, and should be undertaken only if resourses are available for drilling several wells. An isolated well would be of limited value, unless it is to test injectivity, servicing, logging, etc. If a full-scale pilot is to be conducted, then Wabiskaw offers considerable promise, because in this instance heating of the oil sand could be accomplished effectively using the gas and water zones and vertical wells, with the horizontal well serving as a production conduit (Fig. 18(b)). In this manner, we should realize the full potential of a horizontal well as a producer, with efficient heating of the oil sand by relatively conventional, and less costly, means.

Laboratory Studies

Laboratory studies of horizontal wells could be a useful adjunct to field work and numerical simulation. The few studies reported to-date have been qualitative, in some cases relying on analogues. A systematic laboratory investigation of horizontal wells should consist of:

1. Derivation of appropriate equations for steam injection and oil production in a horizontal/vertical well steam injection operation, with detailed description of flow in the vicinity of the horizontal well. The mathematical approach should incorporate a horizontal well into the reservoir flow equations. Such an approach would account for pressure drop in the horizontal well, for instance. These equations should be utilized for deriving scaling criteria for horizontal well operation. It should be possible to construct a variety of models in this manner, e.g. wellbore model, wellbore plus vicinity model, a model of the entire pattern, etc.

2. Construction of a wellbore model, using the scaling criteria derived. This model is more important at this stage than others, mentioned above. Such a model could be operated with simulated fluids at first (e.g. water and air - we are using such an approach), so long as the scaling criteria are satisfied. Later, a high pressure model could be employed. The basic purpose of this model is to determine the flow pattern around the wellbore for both injection and production.

3. Construction of a high pressure steam model, designed to examine injection-production strategies using horizontal-vertical well combinations. The purpose of this model will be to determine horizontal well performance on a pattern basis. The model could be used to examine such specific problems as overlying water and gas formations, such as occur in Wabiskaw.

4. Design and construction of a model of the Horizontal

Annulus Steam Drive (HASD). This process has a number of interesting features that could be useful in Athabasca, in particular that it provides a permanent communication path between the injector and producer, taking full advantage of conduction heating at the same time.

Numerical Simulation

The aforementioned numerical studies of Jain and Khosla (85) are the most useful for horizontal well simulation. The main problem is the lack of a proper representation of a horizontal well. Mathematical model development along the lines of Item 1, above, should make this possible. With that, many well configurations could be investigated. First, the previous studies should be repeated using the more realistic horizontal well model. This would show the importance of flow around the wellbore. The geological detail in the vertical plane is extremely important, as the field results show. Next, a variety of well patterns could be investigated. A few patterns offering some promise for McMurray and Wabiskaw are illustrated in Figs. 17, 18, and 19.

Figure 17 shows placement of drainholes in a pattern. The variables could include pattern size, type, number of drainholes (2 or 4), length, steam injection rate and interval. Figures 18(a) and (b) illustrate a line drive type pattern using vertical and horizontal wells, for the McMurray and Wabiskaw formations, taking account of the shale breaks in the two cases. In the case of McMurray, two horizontal wells should be studied in conjunction with a series of vertical injectors. In the case of Wabiskaw, the use of the overlying gas/water zone and the lower water zone should be examined. Figures 19(a) and (b) show well configurations utilizing horizontal wells for injection and production, with two producers in the case of McMurray, where the lower producer is to produce oil mobilized by conduction heating.

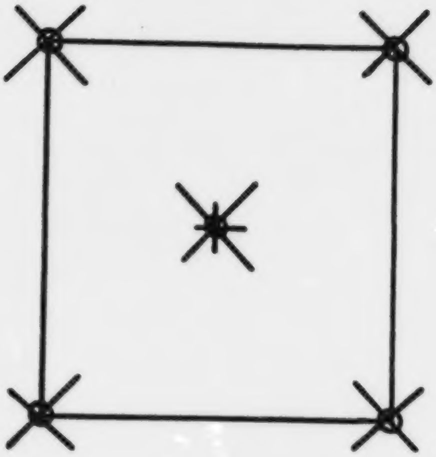


Fig. 17 - Horizontal drainholes - Variables: pattern type, size, number of drainholes (2 Or 4), length, steam placement, rate.

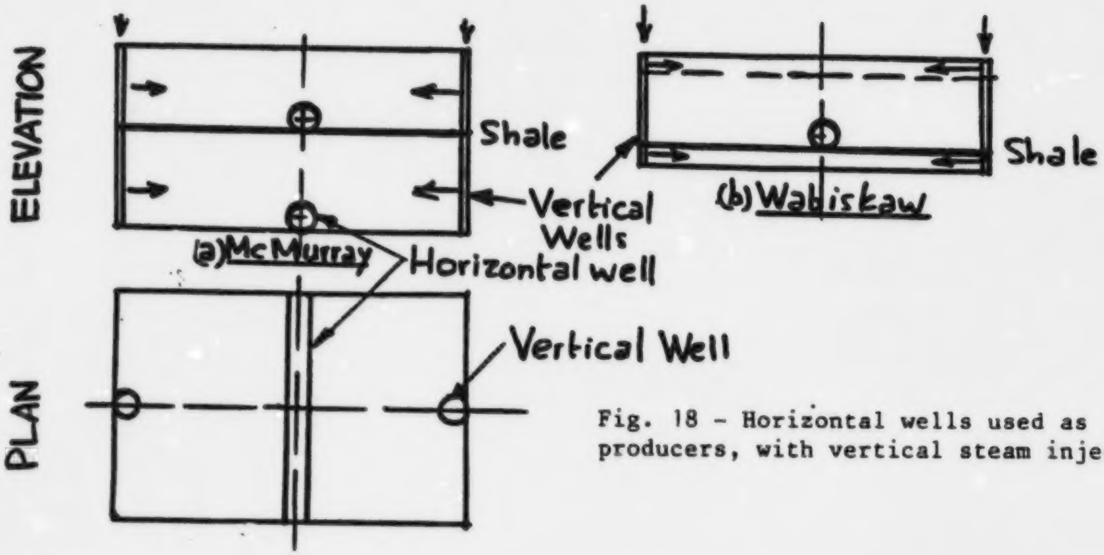

ELEVATION
Shale
Vertical Wells
(a) McMurray
Horizontal well
(b) Wabiskaw
Shale
PLAN
Vertical Well

Fig. 18 - Horizontal wells used as producers, with vertical steam injectors.

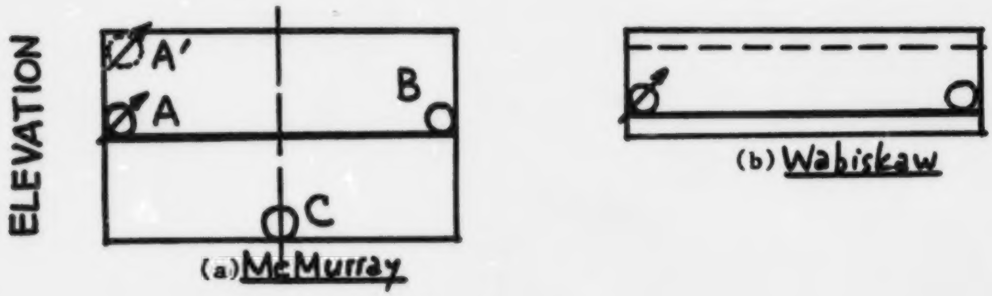

ELEVATION
A'
A
B
C
(a) McMurray
(b) Wabiskaw

Fig. 19 - Horizontal wells used as injectors and producers. (Horizontal well C is placed to capture oil mobilized by indirect heating above).

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3rd Intl. Conf. on Heavy Crude and Tar Sands, Long Beach, July 22-31.

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APPENDIX A

SUMMARIES OF PATENTS ISSUED PERTAINING TO HORIZONTAL WELLS AND RELATED PROCESSES

APPENDIX A

SUMMARIES OF HORIZONTAL WELL PATENTS

4,598,770 Patent - US, Thermal Recovery Method for Viscous Oil
By W R Shu, K J Hartman, Mobil Oil Corp, 8 July 1986 (9)

A thermal oil recovery process in which steam is injected into a heavy oil-bearing formation through a horizontally-drilled injection well and oil is produced through a horizontal production well parallel to the injection well. (author abstract). 11 references.

4,598,770 Patent - US, Thermal Recovery Method for Viscous Oil
By W R Shu, K J Hartman, Mobil Oil Corp, 8 July 1986 (9)

A thermal oil recovery process in which steam is injected into a heavy oil-bearing formation through a horizontally-drilled injection well and oil is produced through a horizontal production well parallel to the injection well. (author abstract). 8 references.

1,202,881 Patent - Canada, Solvent Flooding to Recover Viscous Oils
By J L Fitch, L D Mullins, Mobil Oil Corp, 8 Apr 1986 (14)
[US Patent 4,510,997]

This invention is directed to a method of recovering oil from viscous oil-containing subsurface formations. More particularly, this invention is directed to a hydrocarbon solvent recovery method for recovering oil from subsurface formations that are penetrated by at least one injection well and one production well which extend from the surface of the earth and into the subsurface formation containing viscous hydrocarbons. (excerpt). no references.

4,577,691 Patent - US, Method and Apparatus for Producing Viscous Hydrocarbons from a Subterranean Formation
By W S Huang, S F Chien, Texaco Inc, 25 Mar 1986 (7)

Method and apparatus for thermally stimulating bitumen and other viscous hydrocarbon products from a subterranean formation in which the product is held. A plurality of wells are formed in the layer, which wells extend from the surface into a generally horizontal direction through the productive subterranean layer. The respective wells are spaced vertically apart whereby a thermal stimulating fluid such as steam can be selectively injected into discrete segments of the layer. Such injection will achieve the most effective sweeping action by the stimulating fluid through the productive layer. There results an orderly downward flow of the produced product and a more uniform and efficient distribution of heat in the stimulated formation. (author abstract). 12 references.

4,574,884 Patent - US, Drainage and Downhole Hot Fluid Generation Oil Recovery Method
By J H Schmidt, Atlantic Richfield Co, 11 Mar 1986 (6)

Viscous oil is recovered by a process that increases sweep efficiency and heat and fuel utilization and that reduces well and compression requirements and costs. Initially, fluid pressure communication is created between two horizontal drainhole wells in a manner such that oil is produced during at least a part of the step of creating fluid pressure communication between the wells. Fluid pressure communication may be created by practicing hot aqueous fluid (preferably, steam) huff and puff techniques in one or both of the wells. After fluid pressures communication is created a combustion supporting gas (probably, air), a fuel (preferably, natural gas) and an aqueous fluid are injected into one of the drainhole wells. The fuel is burned downhole in a manner such that hot aqueous fluid (preferably, steam) is formed. The hot aqueous fluid and hot products of combustion are passed directly into the formation in horizontal line drive fashion. These hot fluids follow a horizontally wide sweep pattern which increases heat transfer to the inplace oil and increases oil drainage into the producing well. The process is especially useful in permafrost areas. (author abstract). 11 references.

4,565,245 Patent - US, Completion for Tar Sand Substrate
By D S Mims, R S Allen, Texaco Inc, 21 Jan 1986 (6)

Method and apparatus for recovering hydrocarbons from a subterranean formation in which a well completion, including a well liner, lies in a generally horizontal disposition within the hydrocarbon productive substrate. The liner encloses conductor means for delivering a stream of a hot stimulating agent to the well's remote or injection end, and means for regulating the production of bitumen emulsion from the producing end thereof. A fluid impervious barrier is movably interposed in the well liner between the injection end and the producing end to establish a pressure differential across said barrier thereby directing a flow of stimulating agent into the substrate. Said agent, by liquefying bitumen, creates a pattern of paths along which the mixture flows toward the well's lower pressure producing end. By progressively moving the barrier toward said producing end, the flow path pattern can be extended into a broader area of the substrate. (author abstract). 6 references.

4,558,742 Patent - US, Method and Apparatus for Gravel Packing Horizontal Wells
By W S Huang, A Brown, Texaco Inc, 17 Dec 1985 (7)

A well completion and the method therefor for a wellbore which extends generally horizontally of a subterranean layer comprised primarily of unconsolidated sand particles which hold a viscous hydrocarbon. The completion includes an elongated perforated liner which is positioned in the wellbore. The liner is substantially surrounded by a gravel pack which functions to limit the amount of sand particles which are carried from the subterranean layer into the liner in response to the introduction of a flow of a hot stimulating fluid into the substrate. (author abstract). 5 references.

4,558,742 Patent - US, Method and Apparatus for Gravel Packing Horizontal Wells
By W S Huang, A Brown, Texaco Inc, 17 Dec 1985 (7)

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4,545,435 Patent - US, Conduction Heating of Hydrocarbonaceous Formation
By J E Bridges, A Taflove, IIT Research Institute, 8 Oct 1985 (13)

A waveguide structure is emplanted in the earth to bound a particular volume of an earth formation with a waveguide structure formed of respective rows of discrete elongated electrodes wherein the spacing between rows is greater than the distance between electrodes in a respective row and in the case of vertical electrodes substantially less than the thickness of the hydrocarbonaceous earth formation. Electrical power at no more than a relatively low frequency is applied between respective rows of the electrodes to deliver power to the formation while producing relatively uniform heating thereof and limiting the relative loss of heat to adjacent barren regions to less than a tolerable amount. At the same time the temperature of the electrodes is controlled near the vaporization point of water thereat to maintain an electrically conductive path between the electrodes and the formation. (author abstract). 27 references.

4,535,845 Patent - US, Method for Producing Viscous Hydrocarbons from Discrete Segments of a Subterranean Layer
By A Brown, W S Huang, Y M Shum, Texaco Inc, 20 Aug 1985 (8)

Method for producing viscous hydrocarbon products such as heavy crude oil or bitumen from tar sands, which products must be thermally converted into flowable condition. A discrete vertical subsection of a productive subterranean layer is marginated by a pair of spaced apart vertical wells and a horizontal well that lies substantially horizontal to the vertical wells. Controlled, pressurized flows of a heating medium such as steam are introduced to one of the vertical wells and to the horizontal well, whereby to establish a controlled thermal front. The latter is progressively urged by the pressurized steam, through the discrete subsection and toward the other vertical wells at which hydrocarbon emulsion is produced. (author abstract). 2 references.

1,192,127 Patent - Canada, Method of Assisting Surface Lift of Heated Subsurface Viscous Petroleum
By D J Anderson, Chevron Research Co, 20 Aug 1985 (14) [US Patent 4,480,695]

Method and apparatus are disclosed for the production of bitumen and heavy oil by the use of horizontal and concentric injection/production well casings. The injection string, guided by sliding packers, directs the steam (or other drive fluids) to the desired area in the formation and the produced fluids are lifted to the surface via the annular space between the injection tubing and the outer casing. The movement of the injection string is determined by the feedback from a monitoring system that continuously measures the oil/packer fluid ratio. no references.

1,194,784 Patent - Canada, Cyclic Solvent Flooding to Recover Viscous Oils
By L D Mullins, J L Fitch, Mobil Oil Corp, 8 Oct 1985 (14)

This invention is directed to a method of recovering oil from viscous oil-containing subsurface formations. More particularly, this invention is directed to a cyclic hydrocarbon solvent recovery method for recovering oil from subsurface formations that are penetrated by at least one injection well and one production well which extend downwardly from the surface of the earth into the bottom of the oil-containing formation and then extend horizontally through the formation. (excerpt). no references.

4,533,182 Patent - US, Process for Production of Oil and Gas through Horizontal Drainholes from Underground Workings
By W L Richards, Methane Drainage Ventures, 6 Aug 1985 (9)

A method for collecting oil from a plurality of spaced apart oil-bearing subterranean formations includes the steps of drilling a shaft from the earth's surface to a depth sufficient to intersect a plurality of spaced-apart oil-bearing formations, excavating a working area at selected oil-bearing subterranean formations and thereafter drilling a plurality of generally horizontal boreholes from each of the working areas into the selected oil-bearing subterranean formations. Therafter, oil collection troughs are excavated within each of the working areas to collect oil from the boreholes and conduct the collected oil into a sump from which the oil is raised to the earth's surface utilizing a single lift. During collection and raising of the oil from each of the spaced-apart oil-bearing subterranean formations, the shaft and working areas are sealed. (author abstract). 14 references.

4,532,994 Patent - US, Well with Sand Control and Stimulant Deflector
By P Toma, D A Redford, D B Livesey, R M Coates, Texaco Canada Resources Ltd, 6 Aug 1985 (6)

A well completion and method for improving the productivity of hydrocarbon emulsion from a substrate layer which holds the hydrocarbon. The well completion includes an elongated substantially horizontally disposed liner, the walls of which are perforated to receive the emulsion from the substrate. Operationally, a flow of hot stimulating fluid is injected into the productive layer in a manner to achieve optimum penetration, as well as maximum horizontal sweep thereof. A flowable dam or gravel pack is disposed at the completion remote end and serves to pass a flow of stimulating fluid whereby to achieve the desirable distribution of said stimulating medium into the substrate. However, the gravel pack deters passage of emulsion back into the liner. (author abstract). 5 references.

4,532,986 Patent - US, Bitumen Production and Substrate Stimulation with Flow Diverter Means
By D S Mims, R H Widmyer, Texaco Inc, 6 Aug 1985 (6)

A well completion, and method for recovering heavy hydrocarbons or bitumen from a subterranean formation. The completion includes a well liner which lies in a generally horizontal disposition within a hydrocarbon holding substrate to define the main or primary well. A secondary well which extends to the surface intersects the main well to communicate therewith. Said secondary well includes means to conduct a stream of hot stimulating fluid into the main well. A fluid impervious barrier or flow diverter means positioned within the main well between the injection end and the production end, establishes a pressure differential across the barrier. The barrier urges stimulating agent into the substrate at a desired location, thereby creating a heated path along which the bitumen emulsion flows toward the well's production end. Means is provided in the secondary well to position the impervious barrier from one end of the main well to other. (author abstract). 10 references.

4,523,644 Patent - US, Thermal Oil Recovery Method
By N B Dismukes, 18 June 1985 (12)

A system for recovery of oil, particularly viscous oil, from subsurface formations penetrated by highly deviated or horizontal bore holes by circulating there-through a heated fluid. The heated fluid circulated through a flexible conduit which is pulled into the bore hole by thrust generating means at the forward end thereof. Power to operate the thrust generating means is also conducted through the conduit. Produced oil is returned via the conduit. (author abstract). 7 references.

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4,522,260 Patent - US, Method for Creating a Zone of Increased Permeability in Hydrocarbon-Containing Subterranean Formation Penetrated by a Plurality of Wellbores
By H B Wolcott Jr, Atlantic Richfield Co, 11 June 1985 (6)

A method for creating a zone of increased permeability in a subterranean hydrocarbon-containing formation penetrated by a plurality of wellbores by penetrating the formation with a first wellbore; positioning a plurality of other wellbores about the first wellbore with each of the other wellbores having at least one substantially horizontal borehole extending therefrom into the vicinity of the first wellbore; extending a plurality of substantially horizontal boreholes from the first wellbore into the vicinity of the other wellbores; positioning explosive charges in at least a portion of the boreholes and detonating the explosive charges to produce a rubblized zone between the first wellbore and the other wellbores. (author abstract). 12 references.

4,522,260 Patent - US, Method for Creating a Zone of Increased Permeability in Hydrocarbon-Containing Subterranean Formation Penetrated by a Plurality of Wellbores

By H B Wolcott Jr, Atlantic Richfield Co, 11 June 1985 (6)

A method for creating a zone of increased permeability in a subterranean hydrocarbon-containing formation penetrated by a plurality of wellbores by penetrating the formation with a first wellbore; positioning a plurality of other wellbores about the first wellbore with each of the other wellbores having at least one substantially horizontal borehole extending therefrom into the vicinity of the first wellbore; extending a plurality of substantially horizontal boreholes from the first wellbore into the vicinity of the other wellbores; positioning explosive charges in at least a portion of the boreholes and detonating the explosive charges to produce a rubblized zone between the first wellbore and the other wellbores. (author abstract). 12 references.

4,511,000 Patent - US, Bitumen Production and Substrate Stimulation

By D S Mims, Texaco Inc, 16 Apr 1985 (6)

[This patent is concerned with the design of] a well completion, having an injection end and a recovery end, and method for recovering heavy hydrocarbons or bitumen from a subterranean formation. The completion includes a well liner which lies in a generally horizontal disposition within a hydrocarbon holding substrate. Means for carrying a stream of a hot stimulating fluid from the well's injection end such that said fluid will migrate into the substrate surrounding the liner. A fluid impervious barrier is movably positioned within the well liner between the injection end and the production end thereof, and prompts establishment of a pressure differential across the said barrier. The barrier urges pressurized stimulating agent outwardly into the substrate, thereby creating a heated path along which the bitumen emulsion flows toward the well's lower pressure production end. The barrier is adapted to be repositioned within the liner to adjust the bitumen flow path through the substrate. (author abstract). 7 references.

4,510,997 Patent - US, Solvent Flooding to Recover Viscous Oils

By J L Fitch, L D Mullins, Mobil Oil Corp, 16 Apr 1985 (6)

The proposed hydrocarbon solvent flooding scheme features a pair of horizontal, parallel injection and production wells. Production is initiated by introducing solvent in the injection well until a certain pore volume is reached, followed by a soak period, and a final water drive completes the production cycle. 8 references.

4,508,172 Patent - US, Tar Sand Production Using Thermal Stimulation

By D S Mims, R S Allen, Texaco Inc, 2 Apr 1985 (6)

This patent is concerned with a horizontal well completion design to produce bitumen from a thin formation by steam stimulation. The design consists mainly of a perforated pipe encasing a steam line and a movable liner directing the steam to the desired area in the formation. 4 references.

4,489,782 Patent - US, Viscous Oil Production Using Electrical Current Heating and Lateral Drain Holes

By T K Perkins, Atlantic Richfield Co, 25 Dec 1984 (6)

Improved electrical power utilization and increased oil production per producing well are achieved by specially completing a production well, applying electrical current through the production well to a subsurface formation, and producing oil from said formation. The production well extends essentially vertically from the surface and has one or more drain holes, preferably cased with tubular steel, extending laterally from the longitudinal vertical axis of the wellbore and into and traversing a part of the oil bearing formation. The length of the producing well traversing and being in fluid communication with the formation being substantially greater than the thickness of the oil bearing formation. (author abstract). 8 references.

4,489,782 Patent - US, Viscous Oil Production Using Electrical Current Heating and Lateral Drain Holes

By T K Perkins, Atlantic Richfield Co, 25 Dec 1984 (6)

Improved electrical power utilization and increased oil production per producing well are achieved by specially completing a production well, applying electrical current through the production well to a subsurface formation, and producing oil from said formation. The production well extends essentially vertically from the surface and has one or more drain holes, preferably cased with tubular steel, extending laterally from the longitudinal vertical axis of the wellbore and into and traversing a part of the oil bearing formation. The length of the producing well traversing and being in fluid communication with the formation being substantially greater than the thickness of the oil bearing formation. (author abstract). 8 references.

4,480,695 Patent - US, Method of Assisting Surface Lift of Heated Subsurface Viscous Petroleum

By D J Anderson, Chevron Research Co, 6 Nov 1984 (6) [Canada Patent 1,192,127]

A method and apparatus is described for producing viscous petroleum from a subsurface formation. The apparatus includes a generally horizontal cased well through the subsurface formation with injection and production tubings within the well. The casing is perforated and the inner tubings carry a movable packer and a rotatable agitator. The method comprises injecting a heating and drive fluid for moving heated viscous petroleum through the perforations in the casing and into the well for production to the wellhead. Production is monitored for the ratio of produced packer fluid and viscous petroleum. Based on that ratio, the packer is moved within the casing to positions along the horizontal well to maximize production of petroleum. The rotatable agitator assists in removal from the well bore of formation solids produced with the viscous petroleum. (author abstract). 4 references.

1,173,354 Patent - Canada, In Situ Recovery of Viscous Materials By D E Towson, Canada-Cities Service Ltd, Gulf Canada Ltd, Husky Oil Operation Ltd, Imperial Oil Ltd, Petro-Canada Exploration Inc, 28 Aug 1984 (23)

Radially outward horizontal injection/production wells are drilled from an underground chamber at the bottom of a shaft sunk into an oil sands formation. Cyclic stimulation is used as the recovery technique. Steam may be generated either above ground or in the underground chamber which also serves as a collection center for the produced bitumen. no references.

1,173,355 Patent - Canada, In Situ Recovery of Viscous Materials By D E Towson, Canada-Cities Service Ltd, Gulf Canada Ltd, Husky Oil Operations Ltd, Imperial Oil Ltd, Petro-Canada Exploration Inc, 28 Aug 1984 (24)

Horizontal, parallel injection/production wells are drilled into an oil sands formation from a shaft and tunnel network. Steam stimulation, steamflooding, combustion or miscible flooding may be applied to recover the bitumen depending on the type of reservoir. no references.

1,173,353 Patent - Canada, In Situ Recovery of Viscous Materials By J R L Bherer, D E Towson, Canada-Cities Service Ltd, Gulf Canada Ltd, Husky Oil Operations Ltd, Imperial Oil Ltd, Petro-Canada Exploration Inc, 28 Aug 1984 (23)

Radially outward and upward injection/production wells are drilled from an underground chamber at the bottom of a shaft sunk into an oil sands formation. Cyclic stimulation is used as a recovery technique in this scheme. Steam may be generated either above ground or in the underground chamber which also serves as a collection center for the produced bitumen. no references.

1,173,356 Patent - Canada, In Situ Recovery of Viscous Materials By D E Towson, Canada-Cities Service Ltd, Gulf Canada Ltd, Husky Oil Operations Ltd, Imperial Oil Ltd, Petro-Canada Exploration Inc, 23 Aug 1984 (26)

Parallel, upwardly extending injection/production wells are drilled from a network of tunnels and shaft into an oil sands formation. Steam stimulation, steam flooding, combustion or miscible flooding may be applied to recover the bitumen depending on the type of reservoir. no references.

4,463,988 Patent - US, Horizontal Heated Plane Process
By L S Bouck, E Ozey, R E Worsham, Cities Service Co, 7 Aug 1984 (13)

A process for in situ recovery of a tar sand deposit located beneath the earth's surface. A number of boreholes are drilled laterally from subsurface tunnels into the lower portion of the tar sands formation. Initially as a displacing means such as steam is injected into the boreholes, the tar sands become viscous and gravity flow into the bottom of the boreholes. Continuing to apply steam removes the tar sand deposits located in interstitial crevices between the boreholes thereby allowing the steam to flow laterally through these interstitial crevices to nearby boreholes. The steam rises toward the upper portion of the resources formation to create a horizontal heated plane of steam to further remove tar sand deposits located therein. (author abstract). 7 references.

4,460,044 Patent - US, Advancing Heated Annulus Steam Drive
By L T Porter, Chevron Research Co, 17 July 1984 (11)

A method is disclosed for producing viscous petroleum from subsurface deposits. The method employs a vertical well and a horizontal well through the petroleum deposit. A combination of injection procedures through the horizontal and vertical well heat the viscous petroleum in the annulus around the horizontal well. Successive completion intervals are installed in the horizontal well to produce the heated petroleum. The petroleum is driven by a drive fluid passing through previously produced intervals. (author abstract). 7 references.

1,170,980 Patent - Canada, Method of Recovering Viscous Petroleum Employing Heated Subsurface Perforated Casing Containing a Movable Diverter
By D J Anderson, Chevron Research Co, 17 July 1984 (19) [US Patent 4,368,781]

A movable and inflatable flow diverter is used in a horizontal injection well to control and direct the injection fluids(s) to desired location(s) along the communication path between the injection and the production wells. no references.

4,456,065 Patent - US, Heavy Oil Recovering
By W Heim, F J Wolf, W T Savery, Elektra Energie AG, 26 June 1984 (12)

In this combination thermal/solvent process, a primary borehole is first drilled through the bitumen/heavy oil zone and expanded into a collection chamber in the formation underneath the oil sands. A succession of injection wells and production wells are then drilled in a concentric pattern around the first borehole with a circular pattern of injection wells alternating with a circular pattern of production wells. The injection wells are fitted with electrodes for preheating and pumped with steam to drive the bitumen towards the production wells, the bottom section of which converges towards the drainage chamber where the bitumen is collected and pumped to the surface. 11 references.

1,169,353 Patent - Canada, Hydraulic Mining of Tar Sands
By H S Johnson, Gulf Canada Ltd, 19 June 1984 (22) [US Patent 4,437,706]

This patent proposes a hydraulic mining scheme that can be conducted near surface or underground, uses single or multiple jets, and rigid or flexible hoses for the jets. Separation of bitumen from oil sands is enhanced by the turbulent action of the jet, which can also contain an additive such as sodium chloride to further the separation. no references.

1,167,374 Patent - Canada, Method of Mining an Oil Deposit
By V G Verty, P NG Voronin, E I Gurov, V S Zubkov, A I Obrezkov, V P Tabakov, B B Khvoschinsky, V N Judin, Nauchno-Issledovatelsky Institut, 15 May 1984 (21) [US Patent 4,381,124]

This mine assisted thermal recovery scheme for oil sands claims to achieve better heat efficiency by arranging the horizontal injection and production wells in rows and alternating with each others. no references.

1,167,373 Patent - Canada, Method of Treating Reservoirs Containing Very Viscous Crude Oil or Bitumen
By B T Willman, Esso Resources Canada Ltd, 15 May 1984 (28) [US Patent 4,390,067]

Interwell communication is established by drilling a horizontal borehole connecting an injection and a production well, said borehole is filled with non-porous material and heated to maintain the oil fluid in the vicinity of the flow path. This basic modular arrangement can be used as a building block for an entire producing network. no references.

4,437,706 Patent - US, Hydraulic Mining of Tar Sands with Submerged Jet Erosion
By H S Johnson, Gulf Canada Ltd, 20 Mar 1984 (8) [Canada Patent 1,169,353]

This patent proposes a hydraulic mining scheme that can be conducted near surface or underground, uses single or multiple jets, and rigid or flexible hoses for the hydraulic jets. Separation of bitumen from oil sands is enhanced by the turbulent action of the jet, which can also contain additive such as sodium chloride to further the separation. 19 references.

4,436,153 Patent - US, In Situ Combustion Method for Controlled Thermal Linking of Wells
By F M Carlson, Standard Oil Co, 13 Mar 1984 (7)

The patent proposes a method of controlling an in situ combustion process which comprises injecting oxidant and fuel into components of the injection well in stoichiometric proportions. Thereafter, a combustion zone is initiated at the production well which propagates towards the injection well along the path of a lower portion of the injection well. The injection of the oxidant and fuel provide combustion control, as well as optionally water. (excerpt). 11 references.

4,434,849 Patent - US, Method and Apparatus for Recovering High Viscosity Oils
By J C Allen, Heavy Oil Process Inc, 6 Mar 1984 (13)

Improved methods and apparatus are provided for recovering high viscosity oils from a sub-surface earth formation utilizing horizontal well apparatus. A plurality of horizontal drill holes extend from a large diameter vertical shaft hole into the formation of interest. Steam may be injected into the formation through selectively placed conventional vertical wells terminating within the oil-bearing formation, while oil is recovered from the lateral drill holes. A noncondensible gas or cold water may be injected into the formation subsequent to steam injection to enhance the overall recovery of oil. (author abstract). 11 references.

2,124,278 Patent - United Kingdom, Earth Drilling Apparatus and Method
By B W O Dickinson, R W Dickinson, S O Hutchinson, S C May, C S MacKey, 15 Feb 1984 (24) [Patent Application]

This patent application proposes an apparatus for drilling horizontal wells extending radially outward from a vertical guide pipe. The guidance system consists of a whipstock that allows a 90 degree short-radius turning of the drillhead and pipe. Drilling is achieved by hydraulically fracturing the formation. Oil production by steam or other suitable EOR methods begins once the horizontal wells have been properly completed. no references.

1,158,155 Patent - Canada, Thermal Recovery of Viscous Hydrocarbons Using Arrays of Radially Spaced Horizontal Wells
By B T Willman, Esso Resources Canada Ltd, 6 Dec 1983 (22)

Improved sweep efficiency in bitumen recovery could be achieved by drilling two arrays of horizontal wells radiating outward from a central shaft into the formation, with one array having a longer radius than the other. Steam is first injected through the long-radius wells to establish communication, and bitumen is eventually recovered from the short-radius wells. no references.

1,158,155 Patent - Canada, Thermal Recovery of Viscous Hydrocarbons Using Arrays of Radially Spaced Horizontal Wells
By B T Willman, Esso Resources Canada Ltd, 6 Dec 1983 (22)
[US Patent 4,296,969]

Improved sweep efficiency in bitumen recovery could be achieved by drilling two arrays of horizontal wells radiating outward from a central shaft, with one array having a longer radius than the other. Steam is first injected through the long-radius wells to establish communication, and bitumen is eventually recovered from the short-radius wells. no references.

4,410,216 Patent - US, Method for Recovering High Viscosity Oils
By J C Allen, Heavy Oil Process Inc, 18 Oct 1983 (14)

Improved methods and apparatus are provided for recovering high viscosity oils from sub-surface earth formations. In particular, a large diameter shaft hole is employed and a plurality of substantially horizontal drill holes extend radially from the shaft hole into the formation. It is a feature of this invention to provide vertically spaced drill holes oriented to improve the recovery of the oil. Methods are provided for further enhancing oil recovery by coordinating the injected fluid with the location of injection within the formation. (author abstract). 15 references.

1,154,429 Patent - Canada, Method and Apparatus for Forming Lateral Passageways
By N B Dismukes, 27 Sept 1983 (50)

A neutral buoyancy horizontal drilling system is proposed whereby the drilling bit is activated by a hydraulic fluid circulated in a flexible pipe connecting the bit to the surface equipment. Both drilling bit and fluid have the same density range of 0.9 to 2.7 g/ml. no references.

1,148,854 Patent - Canada, Method and Apparatus for Recovering High Viscosity Oils
By J C Allen, Barber Heavy Oil Process Inc, 28 June 1983 (44) [UK Patent 2,066,333]

The author claims a method and an apparatus to recover high viscosity oil from sub-surface formations. The invention involves a large diameter shaft, a group of drill holes extending radially from the shaft near the top of the formation, and another group of lateral holes drilled near the bottom of the formation. no references.

4,390,067 Patent - US, Method of Treating Reservoirs Containing Very Viscous Crude Oil or Bitumen
By B T Willman, Exxon Production Research Co, 28 June 1983 (15) [Canada Patent 1,167,373]

A method for treating a field containing viscous oil or bitumen for subsequent production is described. The steps central to the process are drilling a horizontal well within the oil-bearing stratum, and heating the oil in the vicinity of the horizontal well to produce a hot liquid corridor. The open borehole is filled and the oil in the heated corridor is displaced from one end to the other. The corridors may be connected in various configurations to effectively displace a high percentage of oil in a particular field. (author abstract). 10 references.

4,385,662 Patent - US, Method of Cyclic Solvent Flooding to Recover Viscous Oils
By L D Mullins, J L Fitch, Mobil Oil Corp, 31 May 1983 (7)

A cyclic solvent injection method is proposed to recover bitumen and heavy oil, wherein the solvent is first pumped in the injection well until breakthrough occurs at the production well, followed by a soak period; the injection cycle then repeats in the reverse direction until breakthrough occurs at the injection well, followed by another soak period; finally, a drive fluid is injected in the injection well to produce the oil/solvent phase. 6 references.

4,384,613 Patent - US, Method of In Situ Retorting of Carbonaceous Material for Recovery of Organic Liquids and Gases
By L B Owen, J F Schatz, U Ahmed, Terra Tek Inc, 24 May 1983 (8)

This patent relates to a two-phase (pyrolysis/combustion) in situ recovery scheme, whereby bitumen is first pyrolysed in situ by a series of heat ducts without burning in order to produce liquid oil fractions and hydrocarbon vapors and gases, followed by an air injection sequence through the same heat ducts to start combustion and clear up coke formed around the ducts. Hydrocarbon products are recovered from a number production wells drilled in the pyrolysis/combustion zone. The cycle is repeated when necessary. 13 references.

4,381,124 Patent - US, Method of Mining an Oil Deposit
By V G Verty, P G Voronin, E I Gurov, V S Zubkov, A I Obrezkov, V P Tabakov, B B Khvoschinsky, V N Judin, 26 Apr 1983 (8) [Canada Patent 1,167,374]

This mine assisted thermal recovery scheme claims to achieve better heat efficiency by arranging the horizontal injection and production wells in rows and alternating with each others. 6 references.

4,368,781 Patent - US, Method of Recovering Viscous Petroleum Employing Heated Subsurface Perforated Casing Containing a Movable Diverter
By D J Anderson, Chevron Research Co, 18 Jan 1983 (7) [Canada Patent 1,170,980]

A method is disclosed for recovering viscous petroleum from subsurface formation, such as tar sands, wherein a substantially horizontal, perforated casing is positioned in the formation and a movable diverter is positioned to direct a hot drive fluid out through the perforations and into the formation to move the viscous petroleum that has been heated by the drive fluid toward the production location. The production is monitored for content of drive fluid and petroleum and the position of the diverter is controlled in accordance with the monitored production to optimize the production of petroleum and to maintain the communication path within the formation between the injection location and the production location. (author abstract). 14 references.

4,296,969 Patent - US, Thermal Recovery of Viscous Hydrocarbons Using Arrays of Radially Spaced Horizontal Wells
By B T Willman, Exxon Production Research Co, 27 Oct 1981 (9)

Normally immobile mineral values are recovered from a subterranean formation by penetrating the formation with an access shaft and drilling two radial arrays of substantially horizontal wells out into the formation from the shaft, one array of wells being substantially shorter than the other array. A mobilizing fluid is injected into the formation via alternate longer wells so that an outer zone of high fluid mobility is created in the formation. Then the mobilizing fluid is injected into all of the longer wells to sweep the mineral values to the shorter wells where such values are recovered. Improved sweep efficiency of the mineral values is achieved thereby. (author abstract). 2 references.

4,296,969 Patent - US, Thermal Recovery of Viscous Hydrocarbons Using Arrays of Radially Spaced Horizontal Wells
By B T Willman, Exxon Production Research Co, 27 Oct 1981 (9)

Normally immobile mineral values are recovered from a subterranean formation by penetrating the formation with an access shaft and drilling two radial arrays of substantially horizontal wells out into the formation from the shaft, one array of wells being substantially shorter than the other array. A mobilizing fluid is injected into the formation via alternate longer wells so that an outer zone of high fluid mobility is created in the formation. Then the mobilizing fluid is injected into all of the longer wells to sweep the mineral values to the shorter wells where such values are recovered. Improved sweep efficiency of the mineral values is achieved thereby. (author abstract). 2 references.

4,257,650 Patent - US, Method of Recovering Subsurface Earth Substances
By J C Allen, Barber Heavy Oil Process Inc, 24 Mar 1981 (14)

This invention relates to methods and systems for recovering high viscosity oils, petroleum substances and other minerals from subsurface earth formations. In particular, one or more large diameter shaft holes are provided which preferably terminate in an enlarged subterranean chamber. A plurality of drill holes provided, with perforated piping which extend radially from the chamber into the formation, and from which oil and the like may be recovered. It is a particular feature of this invention to provide means and methods for injecting a mixture of steam and a noncondensable gas into the drill holes, whereby the driving mechanism of the formation may be selectively maintained or enhanced at the same time the viscosity of the oil in the formation is reduced. (author abstract). 14 references.

More Recovery for Heavy Oils
Oilweek, V 32, N 7, 23 Mar 1981, P 39-40 (2)

A description of Esso Resources Canada Ltd's in situ project based on the gravity drainage principle and recovery of oil by horizontally drilled wells. no references

2,053,328 Patent - United Kingdom, A Method for Continuously Producing Viscous Hydrocarbons by Gravity Drainage while Injecting Heated Fluids
By R M Butler, Exxon Production Research Co, 4 Feb 1981 (21)

A thermal method for recovering normally immobile oil from a tar sand deposit, in which two wells are drilled into the deposit, one for injection of heated fluid and one for production of liquids. Thermal communication is established between the wells. The wells are operated such that heated mobilized oil and steam flow without substantially mixing. Oil drains continuously by gravity to the production well where it is recovered. (author abstract) 2 references.

2,066,333 Patent - United Kingdom, Method and Apparatus for Recovering High Viscosity Oils
By J C Allen, Barber Heavy Oil Process Inc, 30 Dec 1980 (47)

The claimed method and apparatus provide an efficient means for driving oil within an undergound formation vertically toward lateral boreholes which extend radially from a large diameter shaft hole. The apparatus can be used for vertical upward or vertical downward drive depending on the density of oil, the necessity of using a miscible or an immiscible injected fluid, and the particular characteristics of the formation. 2 references.

4,227,743 Patent - US, Method of Thermal-Mine Recovery of Oil and Fluent Bitumens
By L M Ruzin, J A Spiridonov, G S Chuprov, B A Tjunkin, V P Tabakov, 14 Oct 1980 (15)

The invention relates to recovering oil from highly viscous oil-bearing formations, and more particularly, it relates to a method of thermal-mine recovery of oil and fluent bitumens or kerogens. (excerpt). 8 references.

1,072,005 Patent - Canada, Method for Oil Recovery Using a Horizontal Well with Indirect Heating
By R M Butler, Exxon Production Research Co, 19 Feb 1980 (18)

An in situ recovery process using a horizontal injection/production well extending from a vertical shaft. The well consists of a perforated casing with two enclosed concentric pipes. Steam and/or solvent are injected into the formation, and oil is recovered through the perforations. The inner pipes form a closed loop flow path for the heating fluid to volatilize part of the recovered oil so the vapor fractions are returned to dilute the oil in the formation. no references

1,070,611 Patent - Canada, Recovery of Hydrocarbons by In Situ Thermal Extraction
By R M Butler, C C Bombardieri, B A Slevinsky, Exxon Production Research Co, 29 Jan 1980 (24)

An in situ process with a horizontal injection-production well extending from a vertical section of the same into the formation. The well completion includes a perforated casing and two concentric pipes inside the casing. Hot fluids are injected through the annular flow paths between the casing and the pipes and the oil product is recovered through the inner pipe. no references

4,165,903 Patent - US, Mine Enhanced Hydrocarbon Recovery Technique
By J H Cobbs, 28 Aug 1979 (8)

A mine assisted in-situ process where a horizontal shaft is drilled below the oil-bearing strata from a vertical access hole and wells are drilled upwards from one or more stations along the shaft into the formation to recover oil. no references

4,162,808 Patent - US, In-Situ Retorting of Carbonaceous Deposits
By R Kvapil, K M Clews, Gulf Oil Corp, Standard Oil Co, 31 July 1979 (8)

A method of producing fluid fuels by in-situ combustion of carbonaceous deposits in rubblized subsurface retorts. 3 references

4,160,481 Patent - US, Method for Recovering Subsurface Earth Substances
By L J Turk, R O Kehle, HOP Corp, 10 July 1979 (10)

An in-situ cyclic steam injection method in which a vertical shaft is drilled and widened to a chamber when it reaches the deposit. Radial boreholes with perforated pipes then extend outward into the formation and these perforated pipes alternatively serve the purposes of injecting steam into and recovering oil from the formation. 12 references

1,058,070 Patent - Canada, Oil Production Processes and Apparatus
By D B Vandergrift, 10 July 1979 (22) [US Patent 4,099,570]

An in situ process with a vertical well casing with one or more horizontal extensions reaching radially into the formation. The injection and production lines are enclosed within the casing, and the recovered oil is collected from the bottom of the vertical section of the casing. no references

4,153,300 Patent - US, Recovery of Fluid Fuels by In-Situ Retorting of Carbonaceous Deposits
By R Kvapil, K M Clews, Golder Associates, 8 May 1979 (9)

A matrix consisting of parallel rows of in-situ retort chambers, each with rectangular horizontal cross section and funnel-shape bottom, are constructed in subsurface carbonaceous deposits. Air is injected to the top of the chambers so retorting progresses systematically to the bottom of the chambers where gaseous and liquid products are collected and pumped to the surface. 4 references

4,114,689 Patent - US, Recovery of Petroleum
By N B Dismukes, 19 Sept 1978 (6)

Compaction of friable or unconsolidated strata containing petroleum substance is obtained by increasing the mass of material above the reservoir, vibrating various earth strata and alternately raising and lowering the fluid pressure in the reservoir to yield a maximum reduction in porosity of the reservoir matrix material and thus to expel petroleum substance therefrom. Enlargement of well bore and extension thereof as by drilling lateral wells are contemplated as the production of solid reservoir material and recovery of other solids which may be compacted by the above steps and be slurrified and caused to flow to a well bore. (author abstract). 9 references.

4,101,172 Patent - US, In-situ Methods of Extracting Bitumen Values from Oil Sand Deposits
By L C Rabbits, 18 July 1978 (20)

The present invention provides a method of in situ extraction of bitumen from an oil-sands body which method comprises sinking an access shaft through the oil-sands body, driving an access drift in the rock strata underlying the oil-sands body, delineating a rectangular block of oil-sands in said body by drilling and blasting the oil-sands body to provide substantially vertical planes of fractured oil-sands on all four sides of an enclosed mining room capable of retaining liquids and gases under pressure and comprising solid pillar walls, providing generally upwardly extending bores in said block of oil sands from the access drift in the said body, providing perforated pipes in those portions of the bores in said block, the perforations of said pipes being dimensioned to prevent sand particles from said block passing therethrough, increasing the permeability of the block of oil sands within said room by fracturing said block, flooding the mining room with a hot fluid at a temperature and for a residence time sufficient to raise the temperature of the block by an amount to cause the bitumen to become flowable with said fluid and removing the fluid-bitumen mixture so formed from said block, the passage of said fluid through said bed being via said perforated pipes and separating said bitumen from said fluid. (author abstract). 8 references

4,099,570 Patent - US, Oil Production Processes and Apparatus
By D B Vandergrift, 11 July 1978 (7)

A process and apparatus is described for use in the recovery of oil from natural oil-bearing formations such as tar sands by means of thermal energy causing the oil to gravity in the formation into an oil-receiving duct. Oil recovery in relation to installation and operating costs is improved by releasing heat into the formation at the site of the oil-receiving duct. For this purpose a composite heating and oil recovery string is used which is installed along the formation and comprises a tubular casing having oil-entry apertures and, internally of such casing, an oil-receiving duct and a passageway for the circulation of fluid heating medium. (author abstract). 11 references

4,062,404 Patent - US, Method for In Situ Combustion
By J Pasini, L Z Shuck, W K Overbey, US Energy Research and Development Administration, 13 Dec 1977 (5)

This invention relates to an improved in situ combustion method for the recovery of hydrocarbons from subterranean earth formations containing carbonaceous material. The method is practiced by penetrating the subterranean earth formation with a borehole projecting into the coal bed along a horizontal plane and extending along a plane disposed perpendicular to the plane of maximum permeability. The subterranean earth formation is also penetrated with a plurality of spaced-apart vertical boreholes disposed along a plane spaced from and generally parallel to that of the horizontal borehole. Fractures are then induced at each of the vertical boreholes which project from the vertical boreholes along the plane of maximum permeability and intersect the horizontal borehole. The combustion is initiated at the horizontal borehole and the products of combustion and fluids displaced from the earth formation by the combustion are removed from the subterranean earth formation via the vertical boreholes. Each of the vertical boreholes are, in turn, provided with suitable flow controls for regulating the flow of fluid from the combustion zone and the earth formation so as to control the configuration and rate of propagation of the combustion zone. The fractures provide a positive communication with the combustion zone so as to facilitate the removal of the products resulting from the combustion of the carbonaceous material. (author abstract). 10 references

1,020,176 Patent - Canada, Method of Driving a Mine Entry
By A W T Grimley, Kaiser Resources Ltd, 1 Nov 1977 (15)

A shafting and tunnelling mining method where the crushed mined materials are mixed with water to form a slurry and the mixture is transported from the working area to the separation area by means of a flume. no references

4,085,803 Patent - US, Method for Oil Recovery Using a Horizontal Well With Indirect Heating
By R M Butler, Exxon Production Research Co, 25 Apr 1977 (6)

Disclosed is a method for recovering hydrocarbons from a subterranean formation. A heated fluid is injected into the formation by means of a perforated conduit which is positioned substantially horizontally through the formation to heat hydrocarbons within the formation. After a suitable heating period, injection of heat is terminated to permit fluids including formation hydrocarbons to drain from the formation into the conduit. The drained fluids within the conduit are then heated to a temperature such that at least a portion of the drained fluids are vaporized. These vaporized fluids pass from the perforated conduit and into the formation to further heat formation hydrocarbons. Subsequently, formation fluids of reduced viscosity are recovered from the formation through the perforated conduit. (author abstract). 11 references

4,007,788 Patent - US, Recovery of Bitumen from Tar Sands
By J H Striegler, E P Howell, Atlantic Richfield Co, 15 Feb 1977 (4)

A method of recovering bitumen from a subterranean tar sand formation characterized by a plurality of steps. First, a continuous wellbore having a second section thereof contained within the formation and first and third sections thereof extending the second section to the earth's surface is formed. Next, the first and third sections of the wellbore are cased. Thereafter, a heated fluid is circulated through the wellbore contacting the formation to reduce the viscosity of the bitumen contained therein rendering the bitumen mobile. Subsequently, bitumen mobilized by the heated fluid is recovered via the wellbore. (author abstract). 8 references

3,960,213 Patent - US, Production of Bitumen by Steam Injection
By J H Striegler, E P Howell, Atlantic Richfield Co, 1 June 1976 (4)

A method of producing bitumen from a subterranean tar sand formation by the following multi-step method. First, an injection well is drilled to the formation and extended into the formation. Subsequent thereto, a perforated liner is inserted into the injection well extending the entire length thereof and having the perforations provided in the portion of the injection well in contact with the formation. Next, a plurality of production wells are drilled and completed into the formation positioned above and along the length of the injection well. Thereafter, a heated fluid is circulated through the injection well contacting the formation via the perforations and thereby reducing the viscosity of the bitumen contained therein rendering same mobile. Subsequently, the mobilized bitumen is recovered through the plurality of production wells. (author abstract). 15 references

3,960,214 Patent - US, Recovery of Bitumen by Steam Injection
By J H Striegler, E P Howell, Atlantic Richfield Co, 1 June 1976 (4)

A method of recovering bitumen from a subterranean tar sand formation by the following multi-step method. First, an injection well is drilled to the formation and cased. Perforations are provided in the portion of the injection well contacting the formation. Next, a plurality of production wells are drilled and completed into the formation positioned above and along the length of the injection well. Thereafter, a heated fluid is circulated through the injection well contacting the formation via the perforations and thereby reducing the viscosity of the bitumen contained therein rendering same mobile. Subsequently, the mobilized bitumen is recovered through the plurality of production wells. (author abstract). 6 references

3,349,845 Patent - US, Method of Establishing Communication Between Wells
By D R Holbert, B F Grant, Sinclair Oil and Gas Co, 31 Oct 1967 (10)

With the aid of directional/horizontal drilling equipment, a communication path is established between an injection and a production well in an oil shales (or oil sands) formation. Fluidization and subsequent recovery of the hydrocarbons are achieved by injection of hot combustion gases. 6 references.

245,317 Patent - Canada, Method for the Extraction of Bitumen and Other Substances from Natural Deposits of Tar Sands
By W Georgeson, 16 Dec 1924 (6)

Superheated steam is introduced at the lower limit of an oil sands formation. The heated bitumen rises gradually to the top of the formation to be recovered while sand particles settle eventually below the oil. no references

BECHTEL'S DRAINHOLE DRILLING TECHNOLOGY

OVERALL SCHEMATIC

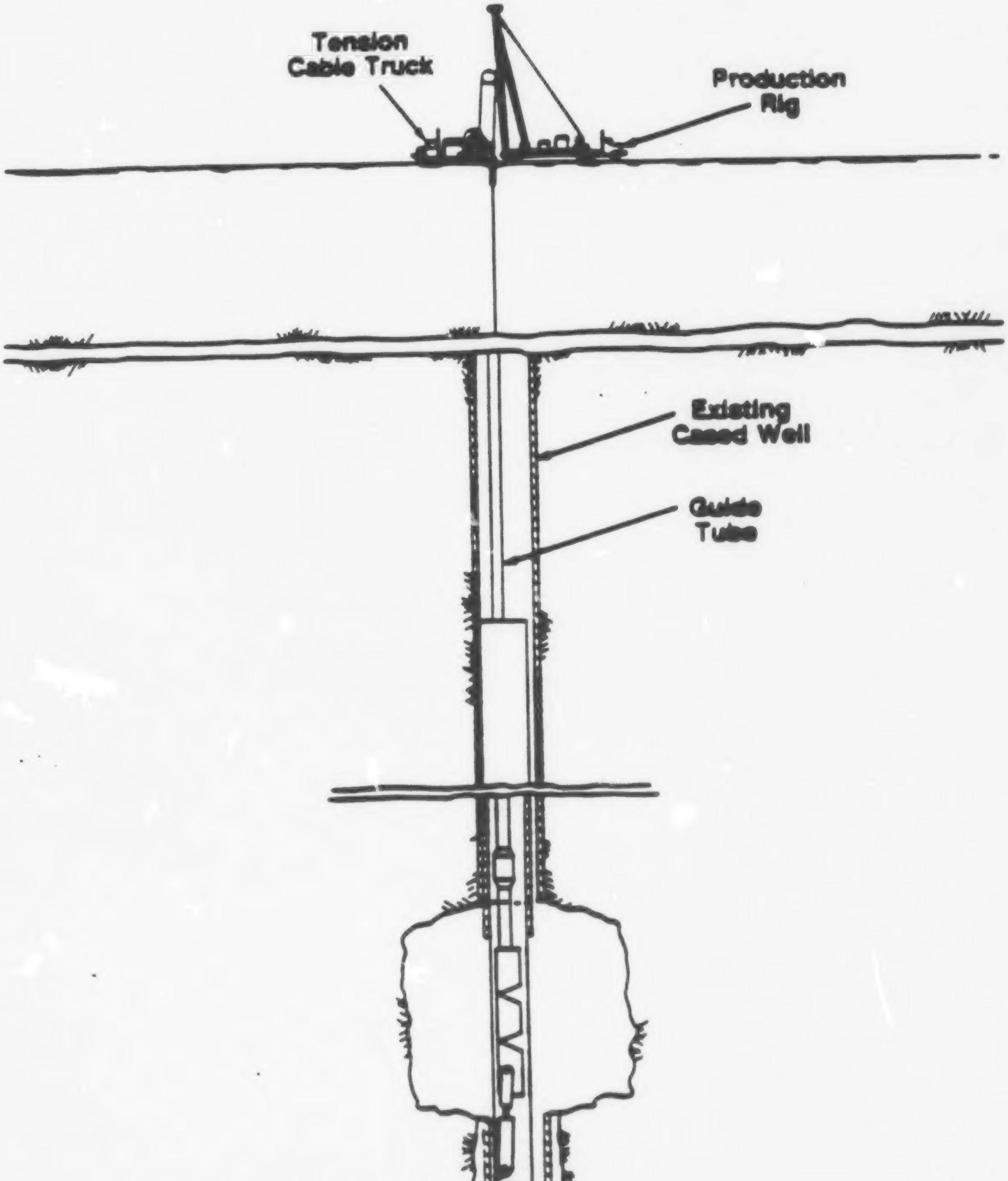
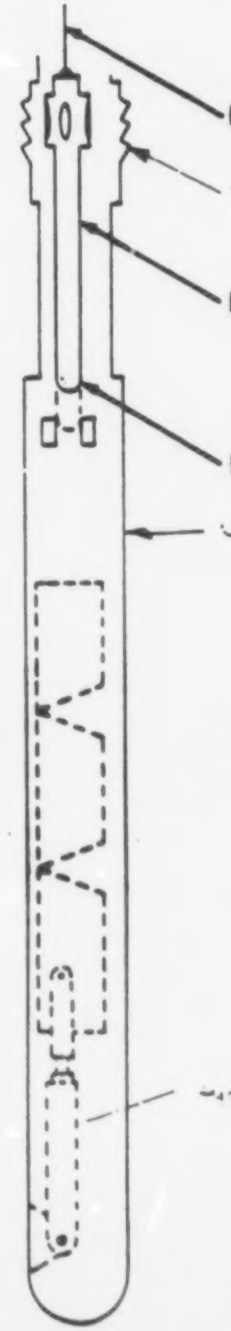
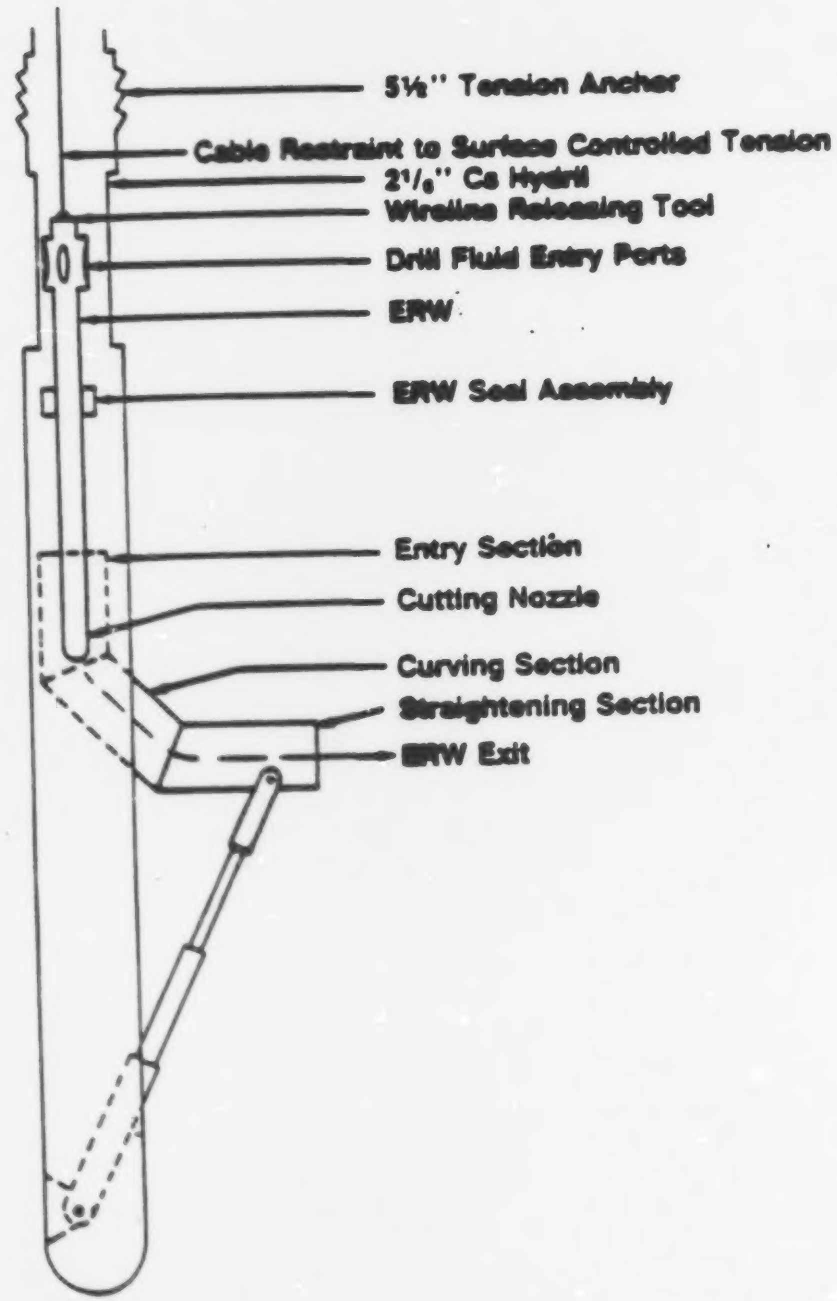

Tension Cable Truck
Production Rig
Existing Cased Well
Guide Tube

Fig. #1

LOADING ERW AND CABLE RESTRAINT ATTACHMENT


Restraint Cable
[illegible]
ERW
Drilling Head
[illegible]
[illegible]

DOWNHOLE WHIPSTOCK ASSEMBLY



5½'' Tension Ancher
Cable Restraint to Surface Controlled Tension
2 1/8'' Cs Hydril
Wireline Releasing Tool
Drill Fluid Entry Ports
ERW
ERW Seal Assembly
Entry Section
Cutting Nozzle
Curving Section
Straightening Section
ERW Exit

F[illegible]

DOWNHOLE WHIPSTOCK ASSEMBLY

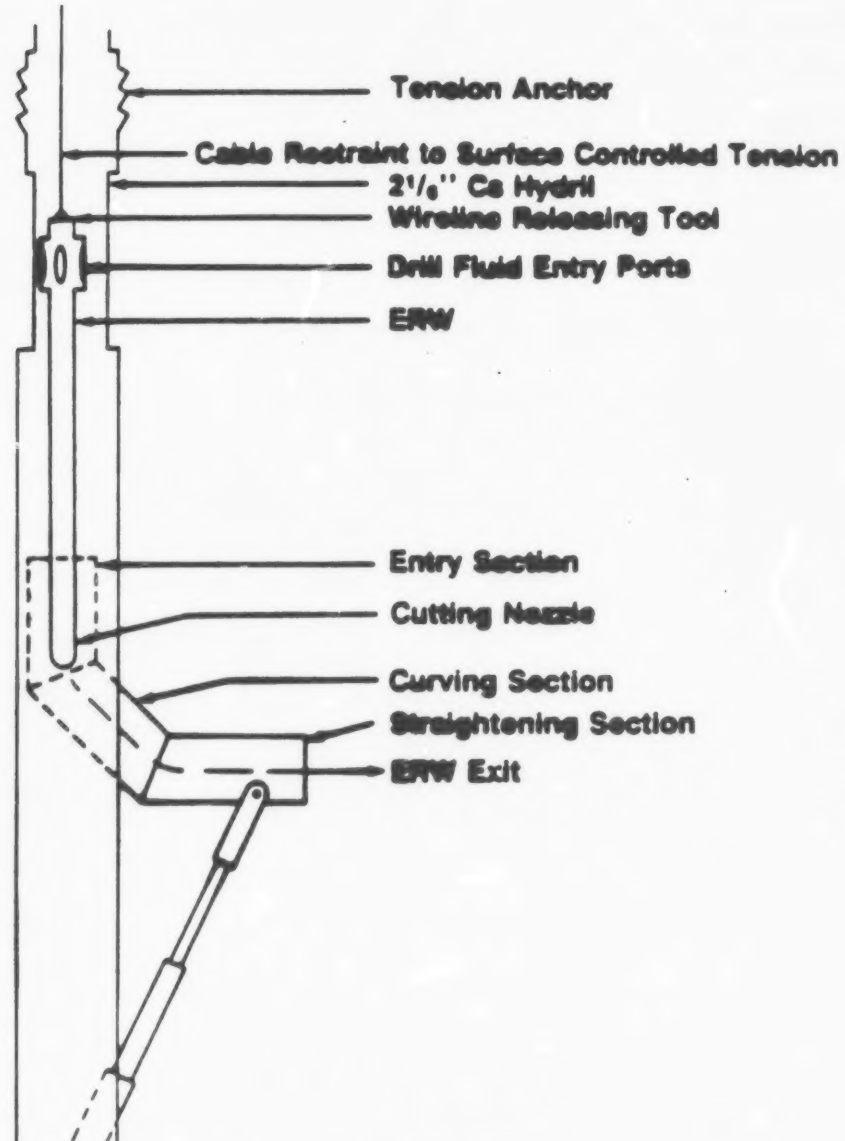
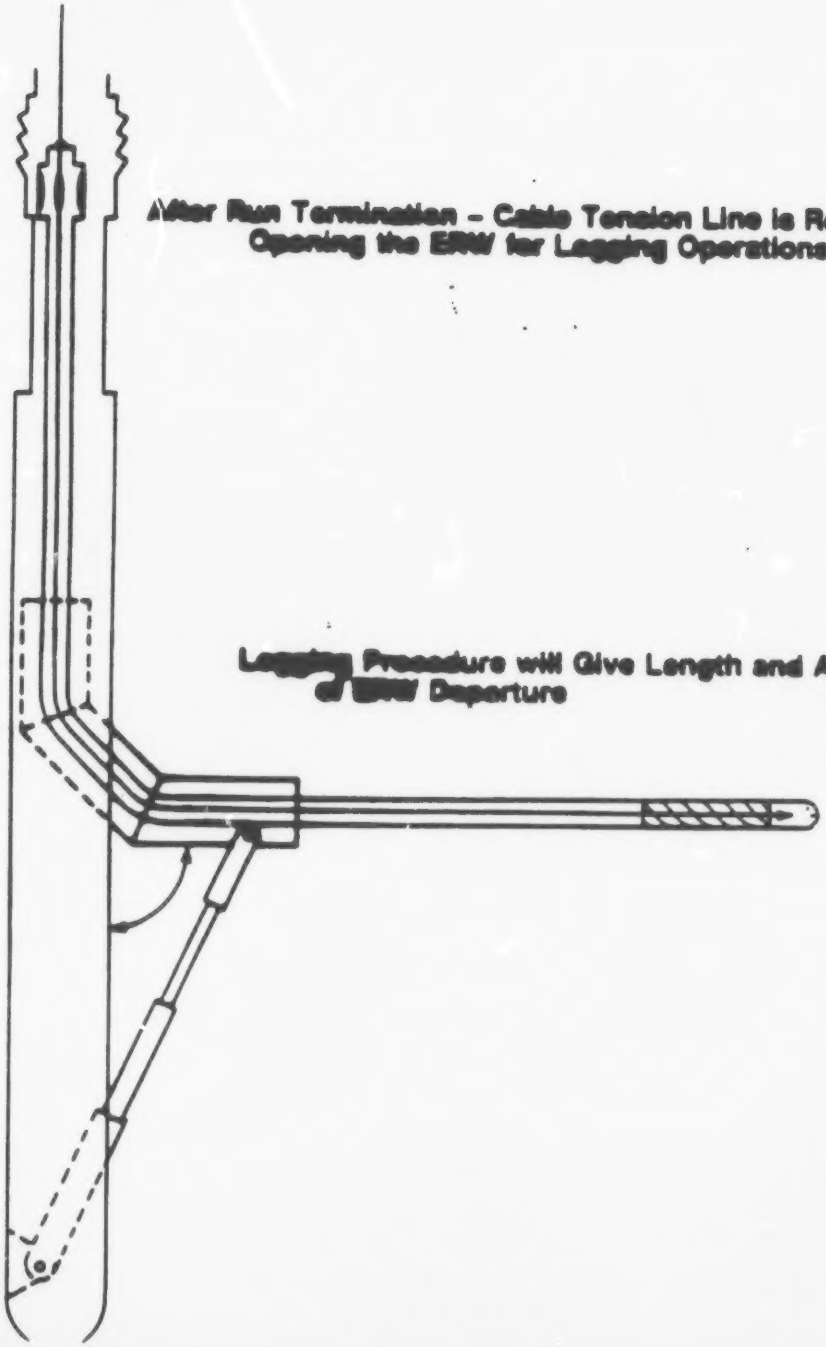

Tension Anchor
Cable Restraint to Surface Controlled Tension
$2^{7}/_{8}$'' Cs Hydril
Wireline Releasing Tool
Drill Fluid Entry Ports
ERW
Entry Section
Cutting Nozzle
Curving Section
Straightening Section
ERW Exit

Fig #7

RELEASING CABLE FROM ERW AND LOGGING PROCEDURE

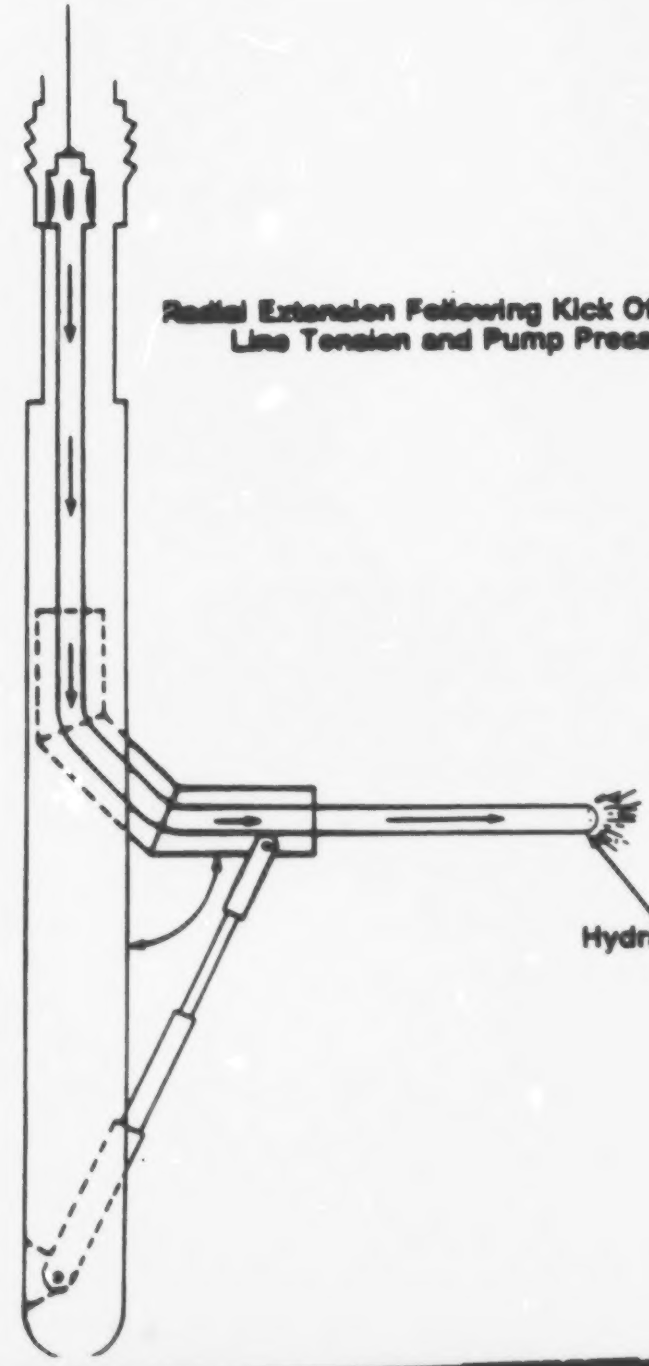


After Run Termination – Cable Tension Line is Released Opening the ERW for Logging Operations

Logging Procedure will Give Length and Angle of ERW Departure

Fig. 8

DRILLING THE RADIAL

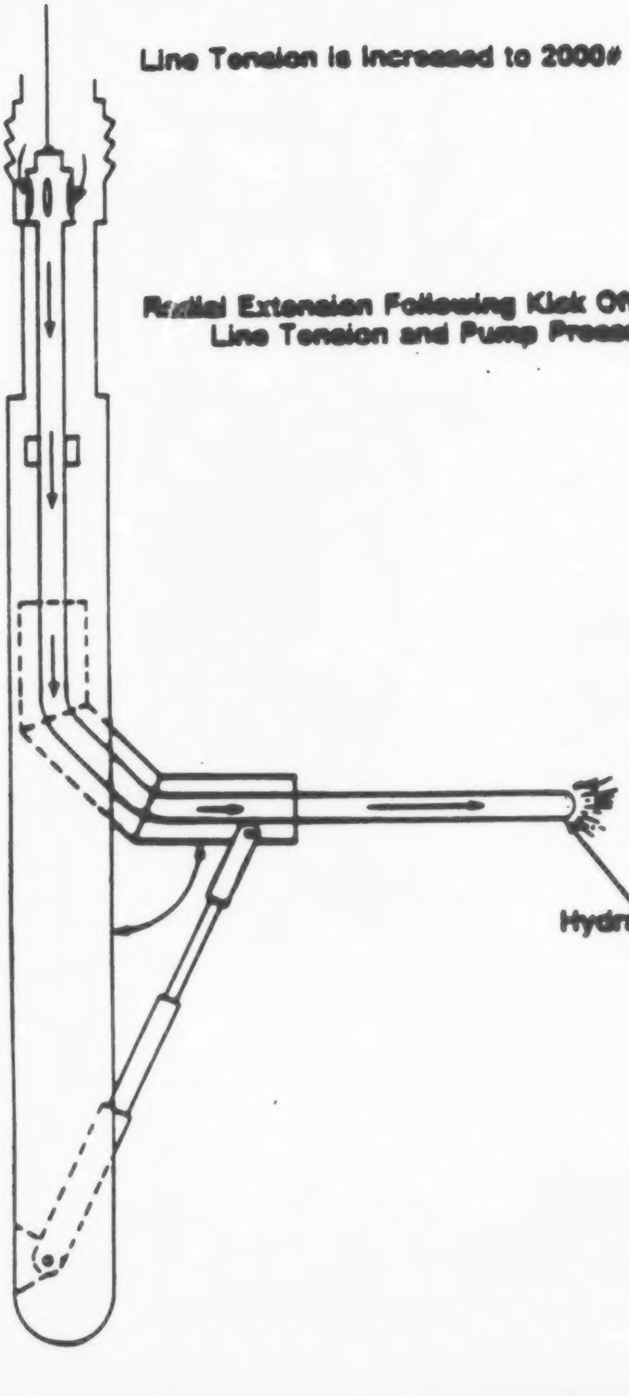


Radial Extension Following Kick Off is Controlled by Line Tension and Pump Pressure Changes

Hydraulic Jet Cutting
Drill Head

F: =6

DRILLING THE RADIAL



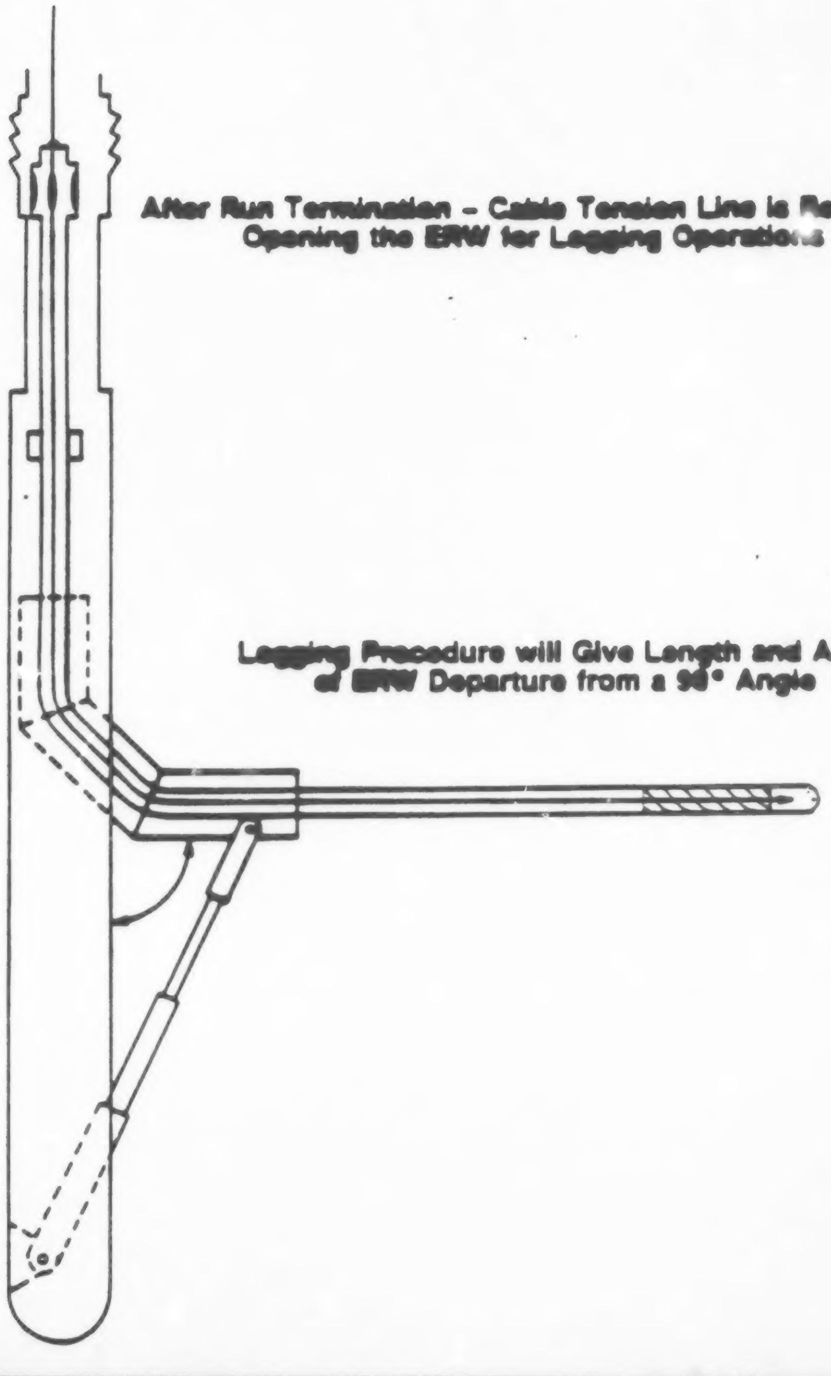
Line Tension is Increased to 2000#

Radial Extension Following Kick Off is Controlled by Line Tension and Pump Pressure Changes

Hydraulic Jet Cutting Drill Head

Fig # 7

RELEASING CABLE FROM ERW AND LOGGING PROCEDURE



After Run Termination – Cable Tension Line is Released
Opening the ERW for Logging Operations

Logging Procedure will Give Length and Angle
of ERW Departure from a 90° Angle

Fig #9

CUTTING ERW AND RETRIEVING RETRACTED WHIPSTOCK

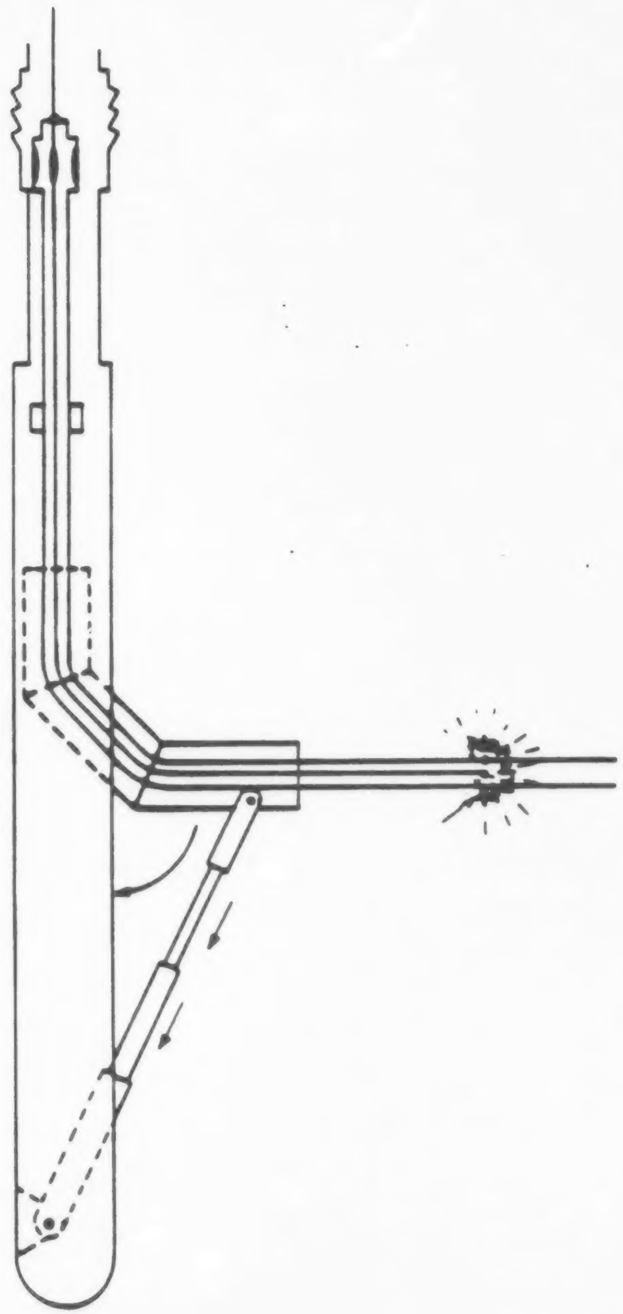


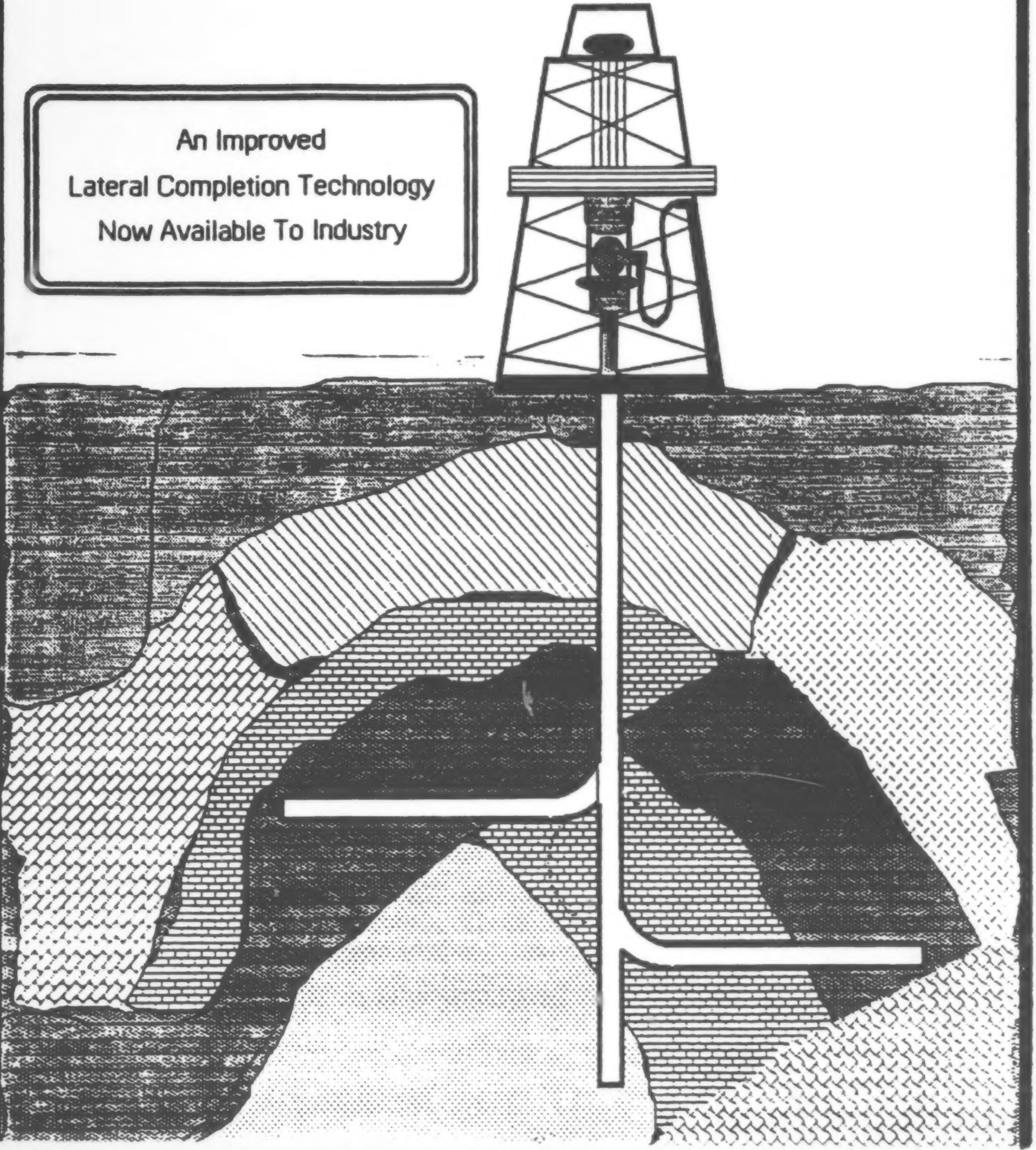
Fig #9

attachment

Eastman Whipstock Inc.

Lateral Drilling Systems

An Improved
Lateral Completion Technology
Now Available To Industry



Eastman Whipstock

a PETROLANE COMPANY

Lateral Drilling Systems

An Improved
Lateral Completion Technology
Now Available To Industry

- Over 180 laterals completed totaling over 40,000 feet.
- Laterals completed in over 50 oil, gas, and mining wells.
- Multiple laterals drilled from a single wellbore.
- Geologic formations drilled:
  - calcareous shales
  - siliceous shales
  - chalks
  - dolomite
  - limestones
  - siltstones
  - sandstones
  - conglomerates
  - evaporite beds

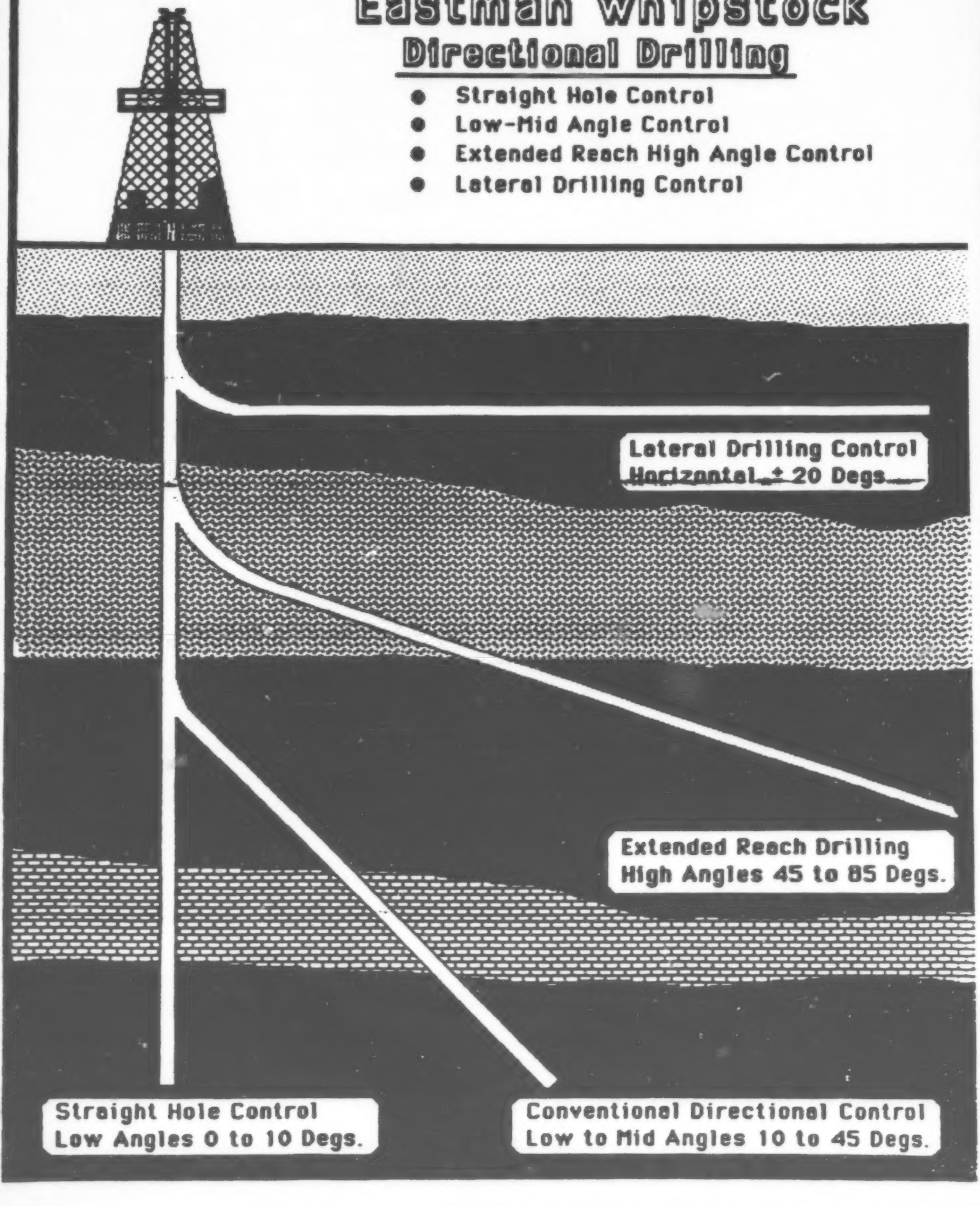
- Compatible with conventional rotary rigs, drilling fluids and rig crews.
- Ability to work in new wells or re—enter existing wells.
- Ability to work from vertical or deviated wells.
- Working depths to date; up to 10,000 feet.
- Maximum length drilled to date 730 feet.
- Multiple laterals per well.

- On—site job supervision and support staff.
- All special tools and equipment furnished.
- Adaptation of system to special needs.
- Directional surveys.
- Special permitting and planning assistance if needed.
- Contractual flexibility.

Eastman Whipstock

Directional Drilling

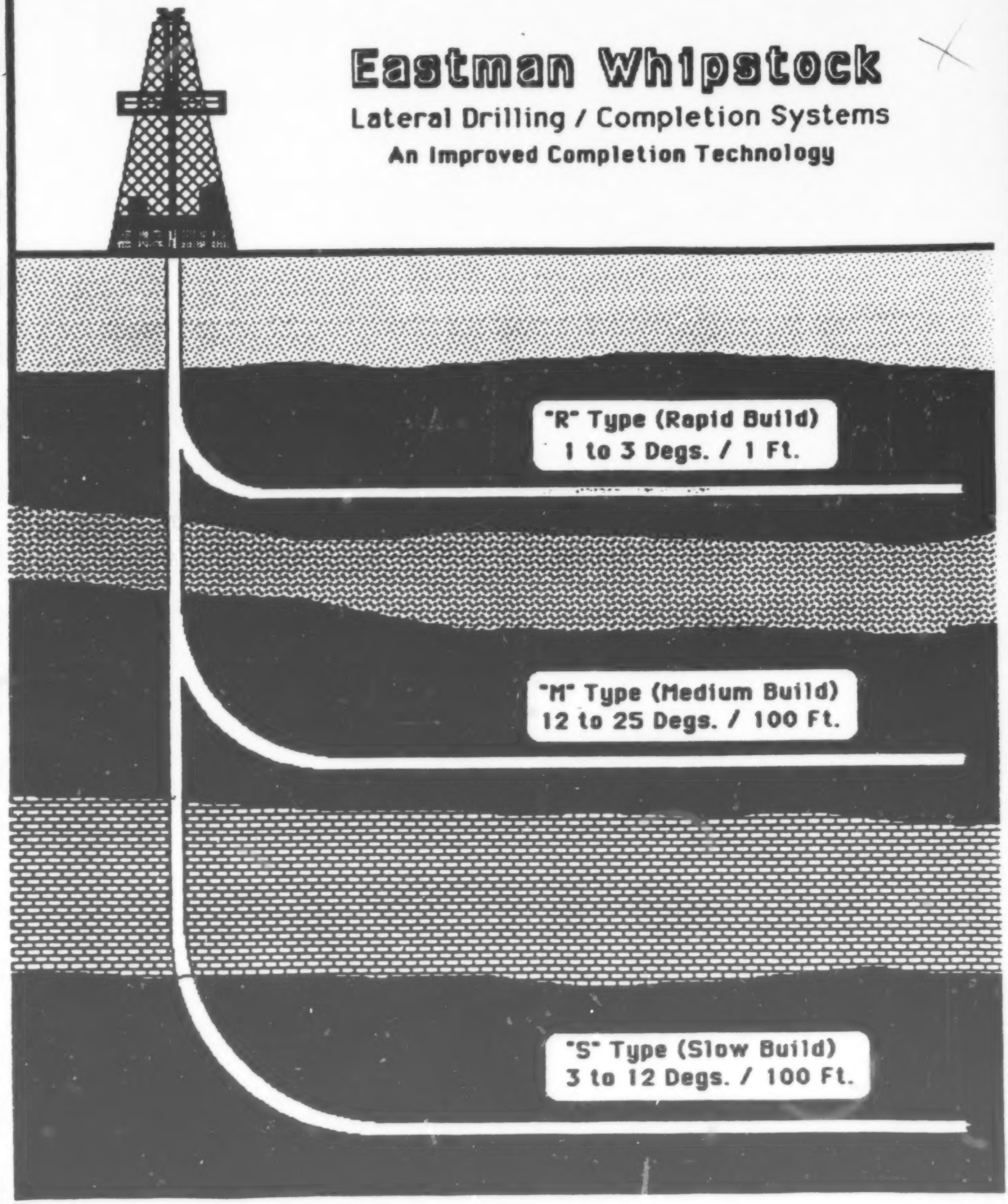
- Straight Hole Control
- Low-Mid Angle Control
- Extended Reach High Angle Control
- Lateral Drilling Control


Lateral Drilling Control
Horizontal ± 20 Degs.
Extended Reach Drilling
High Angles 45 to 85 Degs.
Straight Hole Control
Low Angles 0 to 10 Degs.
Conventional Directional Control
Low to Mid Angles 10 to 45 Degs.

Eastman Whipstock

Lateral Drilling / Completion Systems

An Improved Completion Technology

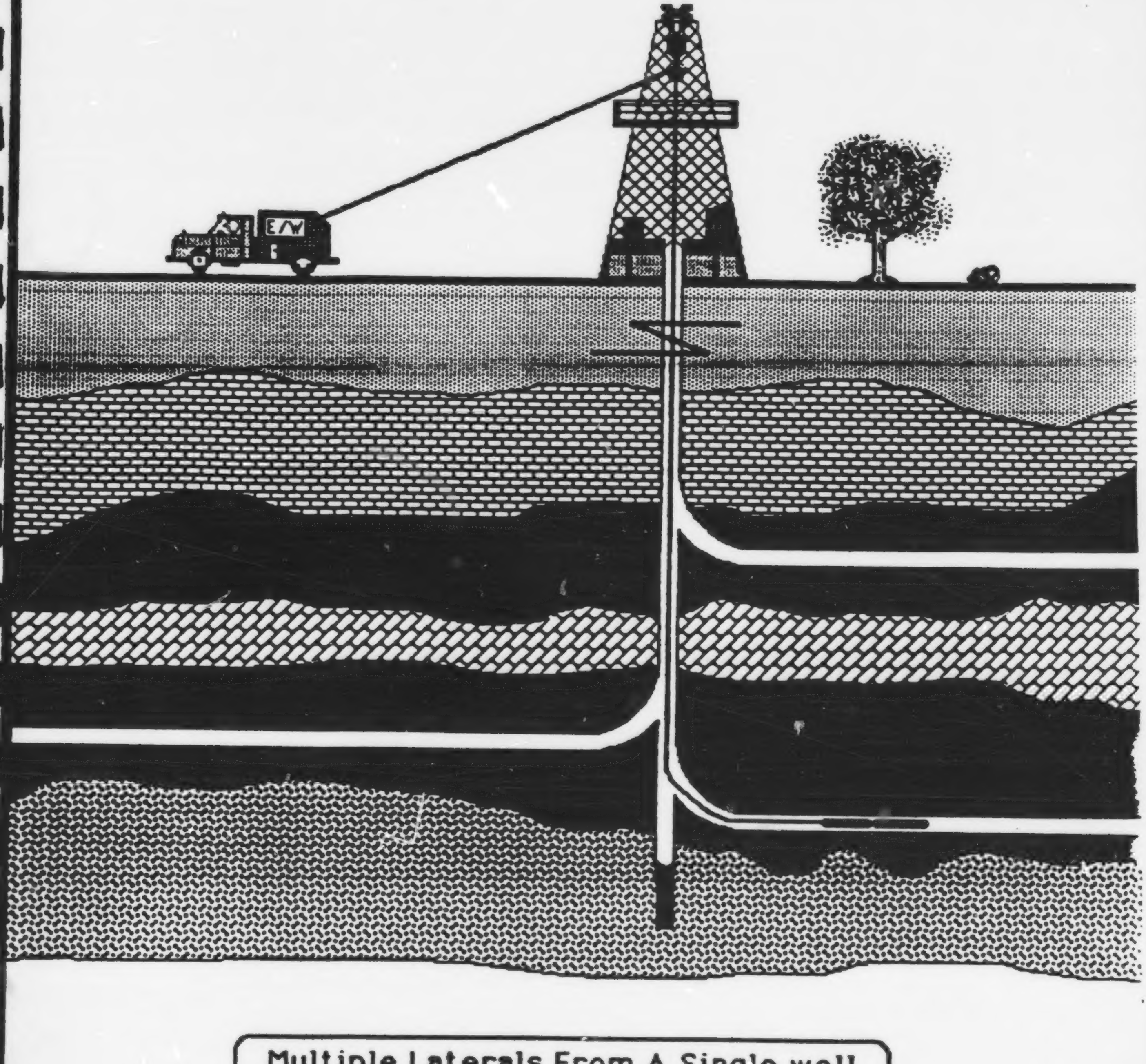


"R" Type (Rapid Build)
1 to 3 Degs. / 1 Ft.
"M" Type (Medium Build)
12 to 25 Degs. / 100 Ft.
"S" Type (Slow Build)
3 to 12 Degs. / 100 Ft.

Eastman Whipstock

Lateral Drilling / Completion

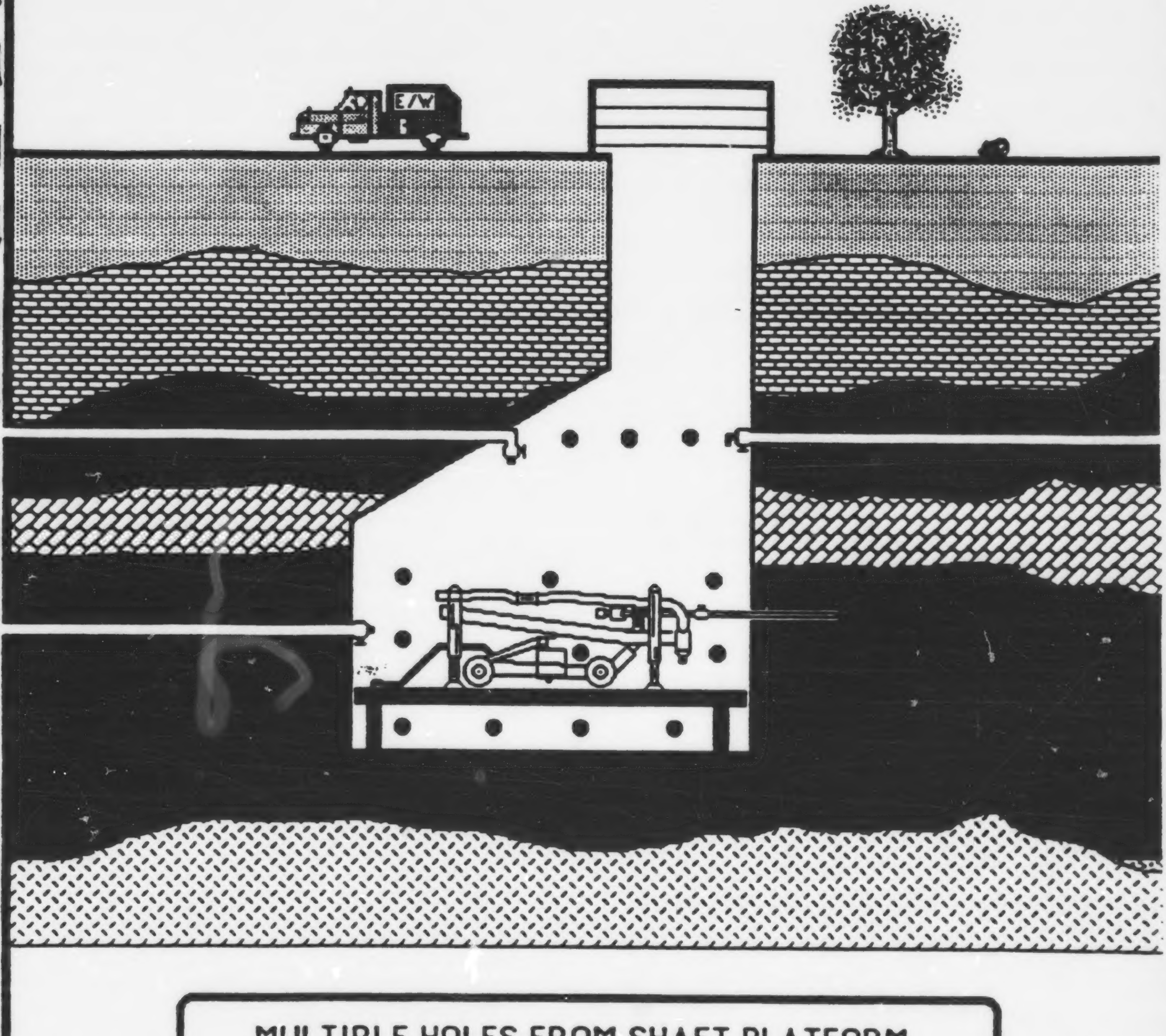
A PROVEN METHOD FOR INCREASING DRAINAGE



Multiple Laterals From A Single well
or
Multiple Laterals In A Single Zone

Horizontal Drilling

Oil Mining

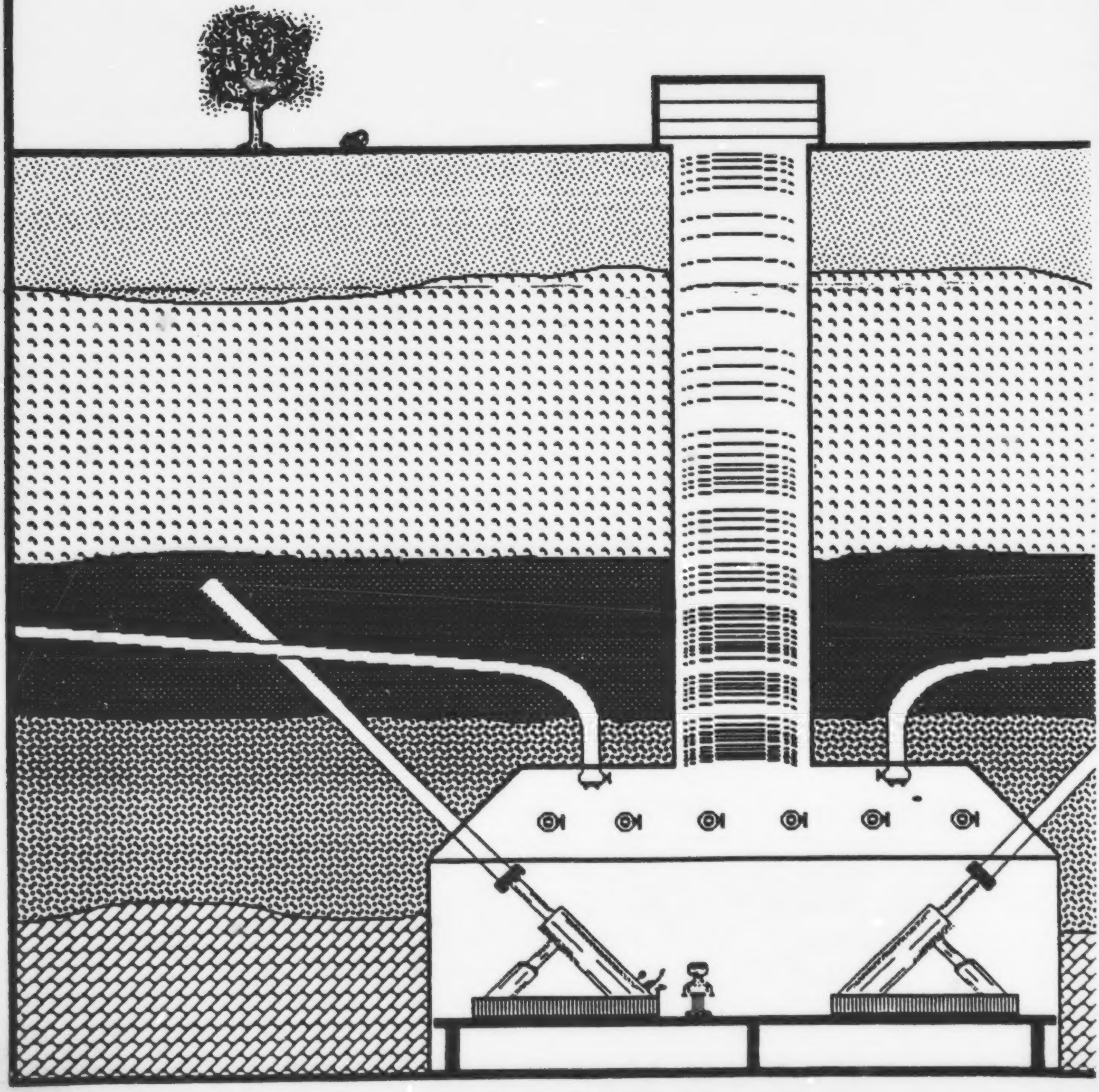


MULTIPLE HOLES FROM SHAFT PLATFORM

Eastman Whipstock

Lateral Drilling / Completion

OIL MINING

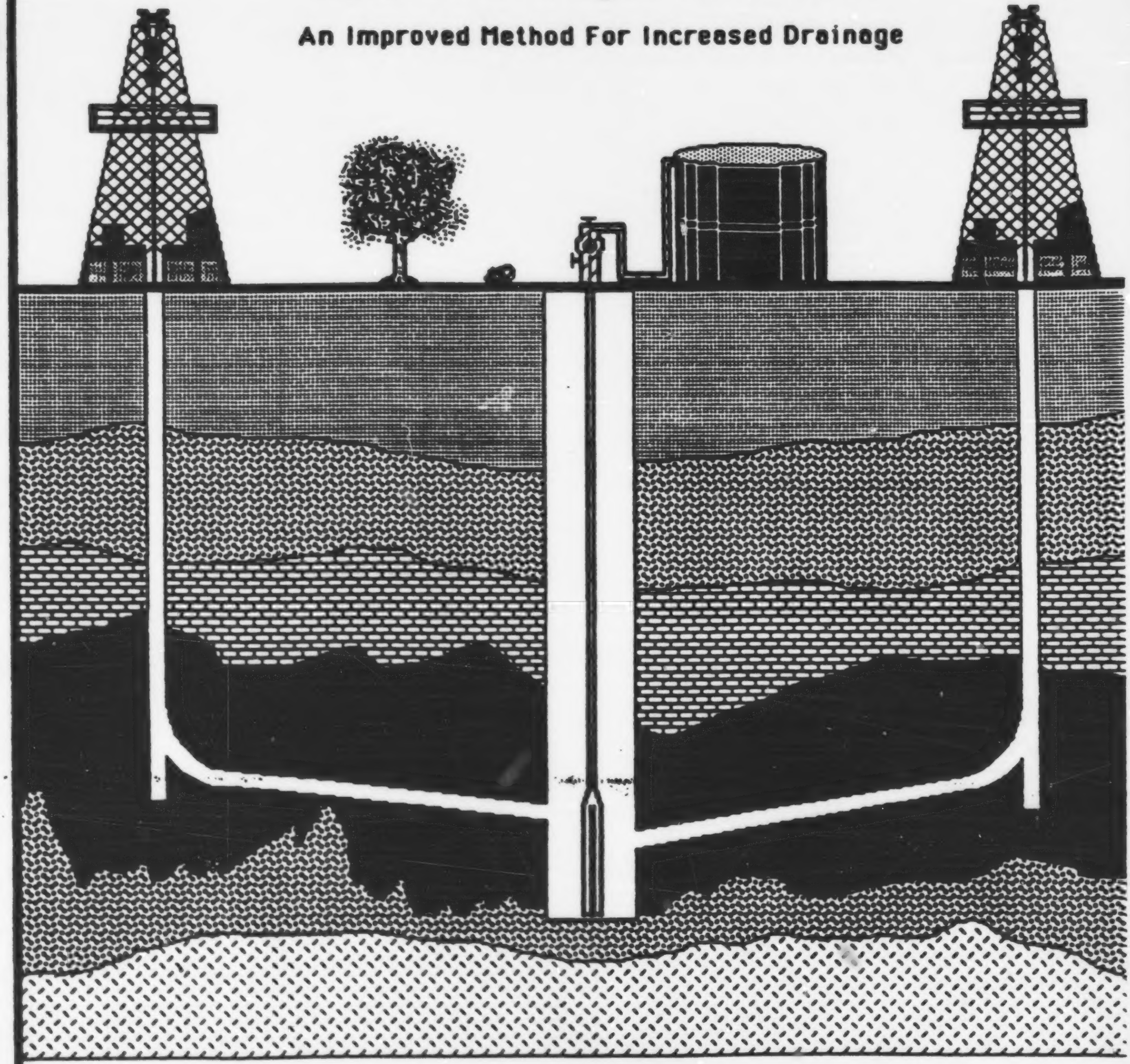


8.

Eastman Whipstock

Lateral Drilling / Completion

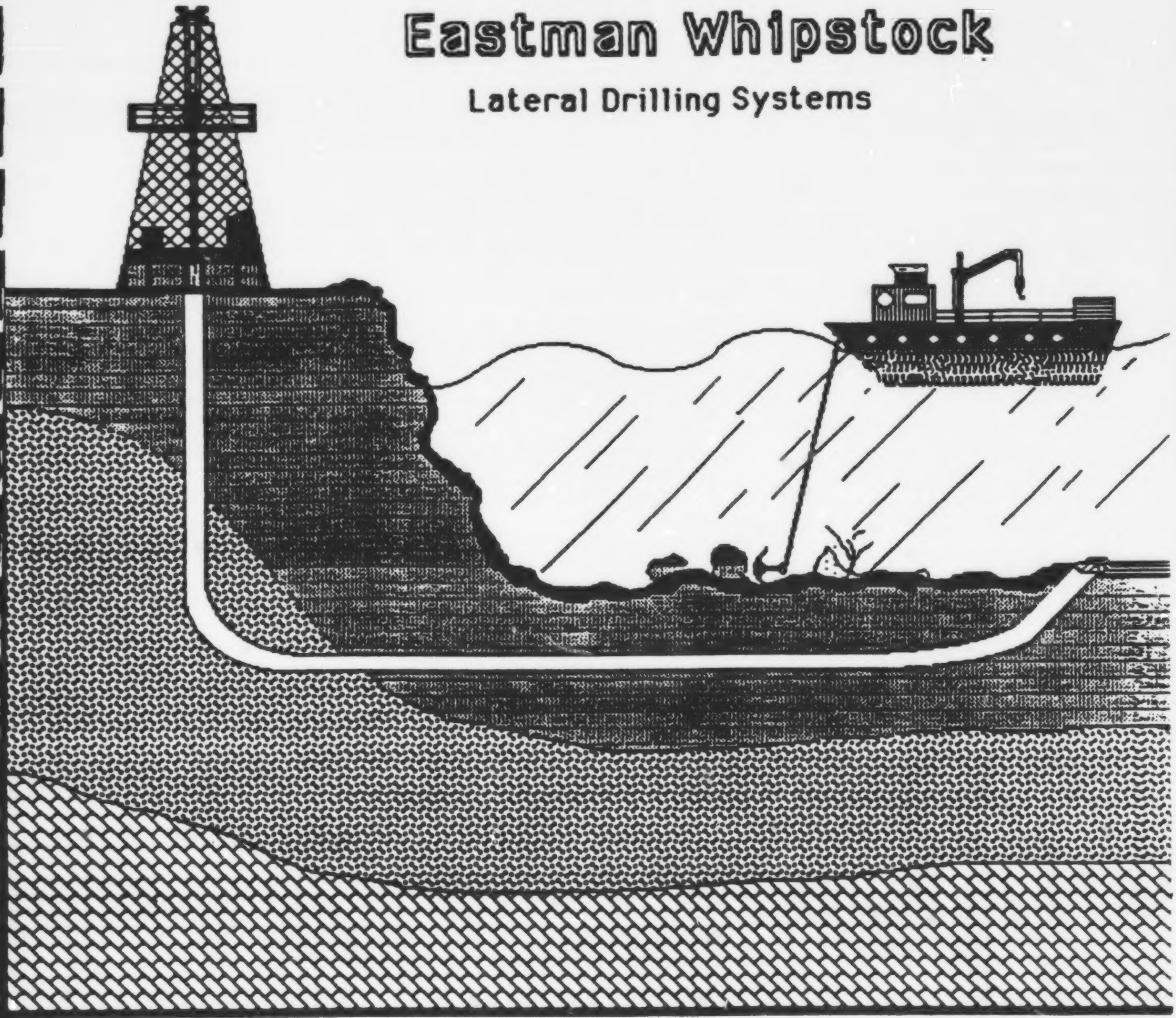
An Improved Method For Increased Drainage



SINGLE PRODUCTION WELL ACCOMMODATES MULTIPLE DRAINAGE WELLS

Eastman Whipstock

Lateral Drilling Systems



- PIPELINE RIVER CROSSINGS
- WATER RUNOFF CHANNELING
- URBAN CONDUIT DRILLING
- SOLUTION MINING PROJECTS
- INSITU PRODUCTION
- WASTE STORAGE

HISTORY

1. 50 year old concept
2. Mid 50's - interest spurred by Zublin and Eastman
3. Continued development hampered by inadequate technology and poor economic conditions
4. Early 80's - Renewed interested brought about by improved economic incentives, increased production demands, modern technology and a better understanding of reservoir behavior.
    - Elf Aquitaine
    - Texaco
    - Esso
    - Arco
    - Texas Eastern

PURPOSE AND OBJECTIVES

1. Enhance conventional and non-conventional recovery of oil and gas.
    - Fractured reservoirs
    - Low energy reservoir
    - Low permeability formation
    - Coning problems
2. Simplicity
    - Simple technology
3. Conventional surface equipment.
    - Eliminate the need for special surface equipment
    - Utilize conventional crews
    - Rotary rig or workover rig capabilities
4. Flexibility
    - New well or workover application

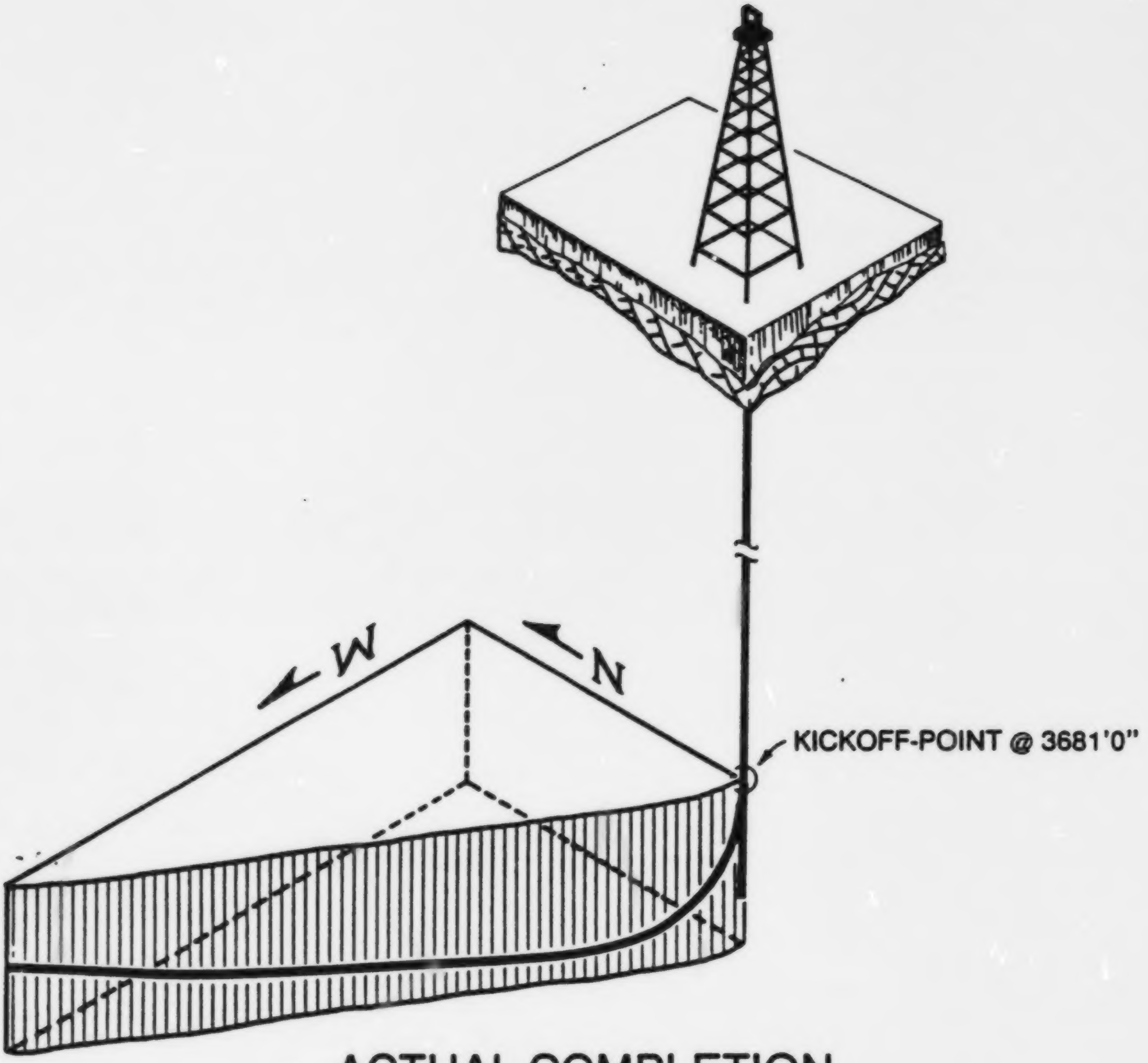
DEVELOPMENT

- Development for in-house use, 1979
- Market analysis, 1983
- Total commitment to service, 1984

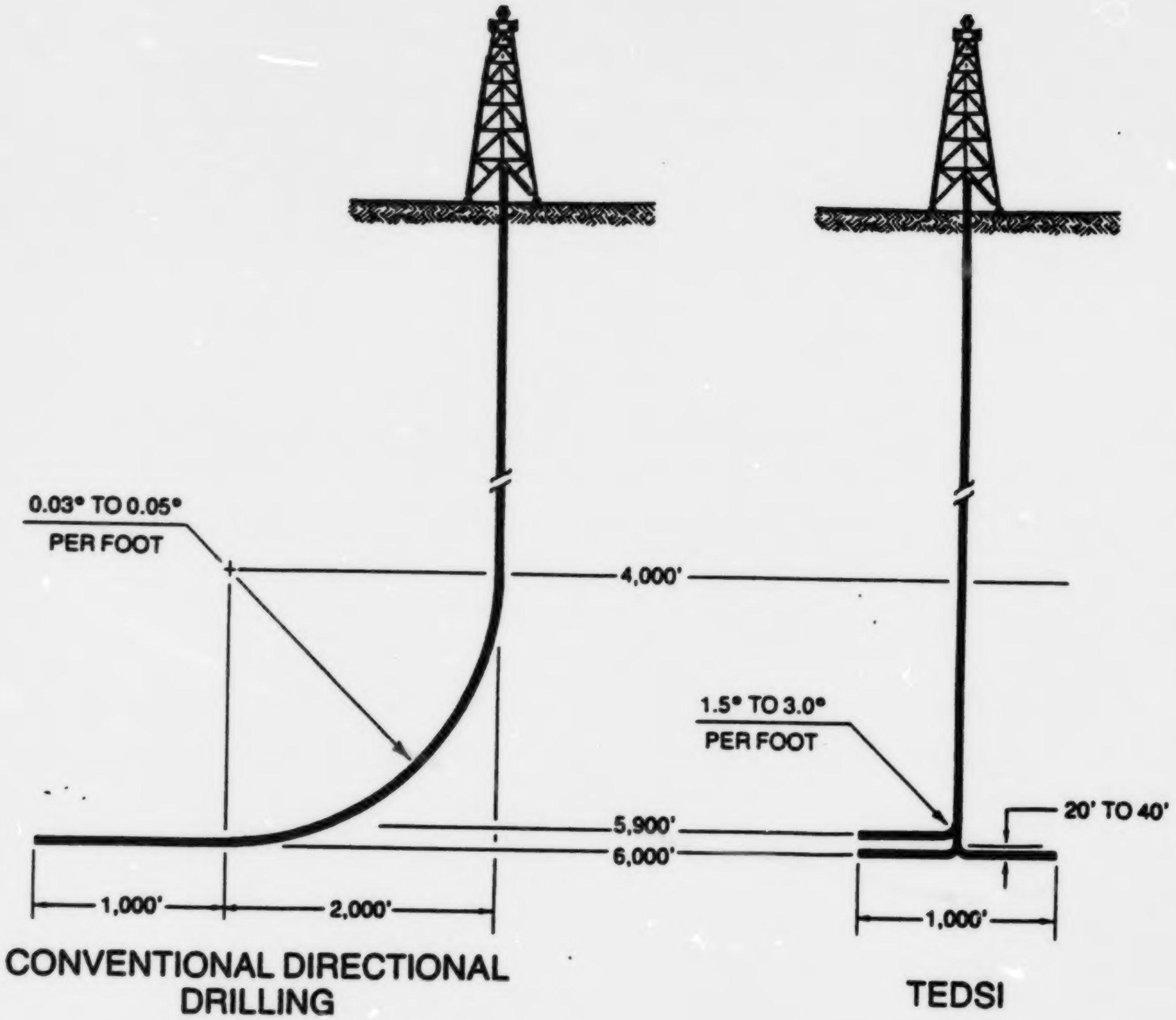
1. Rotary rig and workover capabilities.
   - Rotary string
   - No down hole motor
   - Conventional crews & equipment
   - Rotate using power swivel

2. Drilling fluid flexibilities
   - Mud
   - Foam
   - Air/Mist
   - Air vs. mud

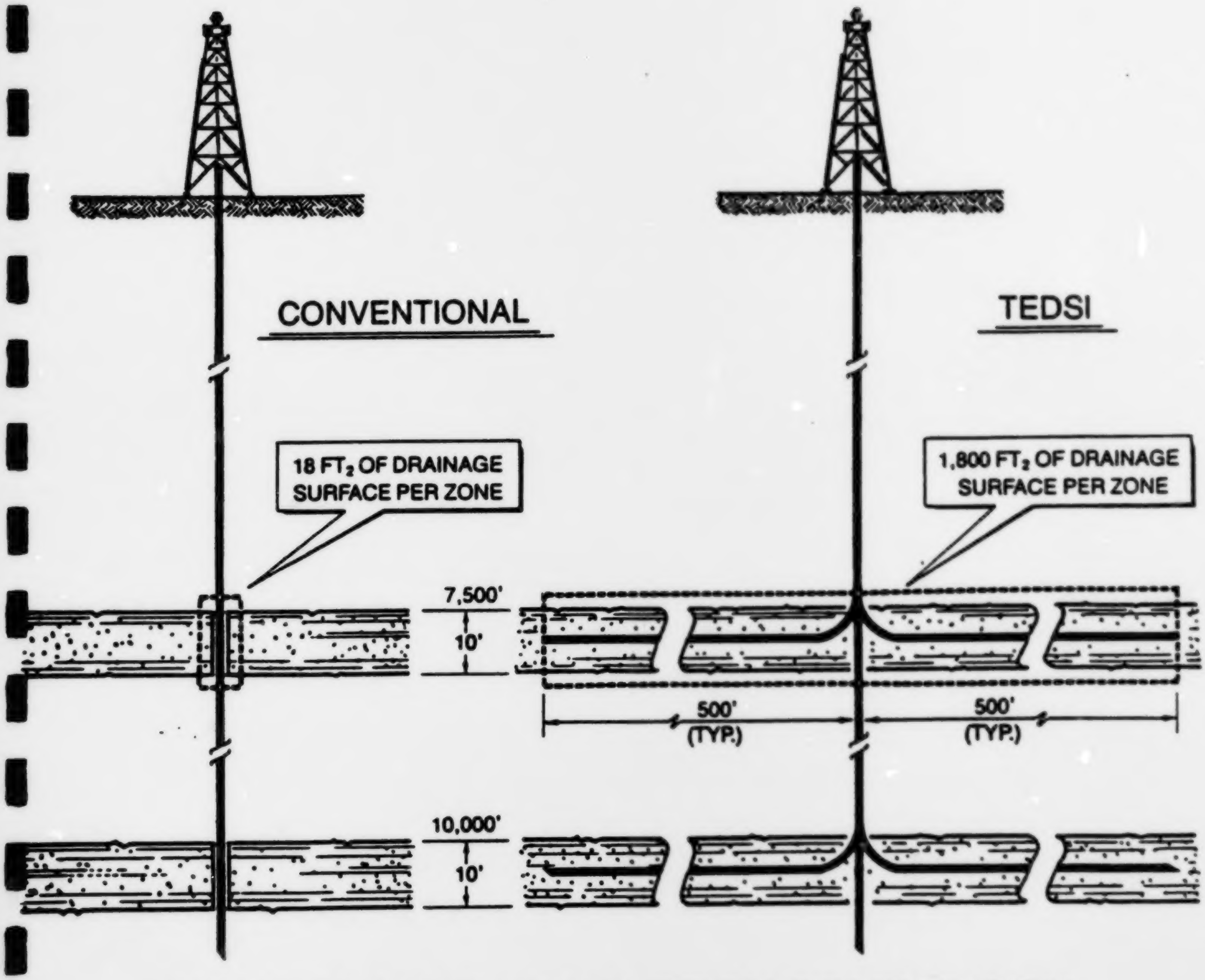
3. Type of well departure
   - Window
   - Section (20–30 foot)
   - Open hole
   - Off bottom


W
N
KICKOFF-POINT @ 3681'0"

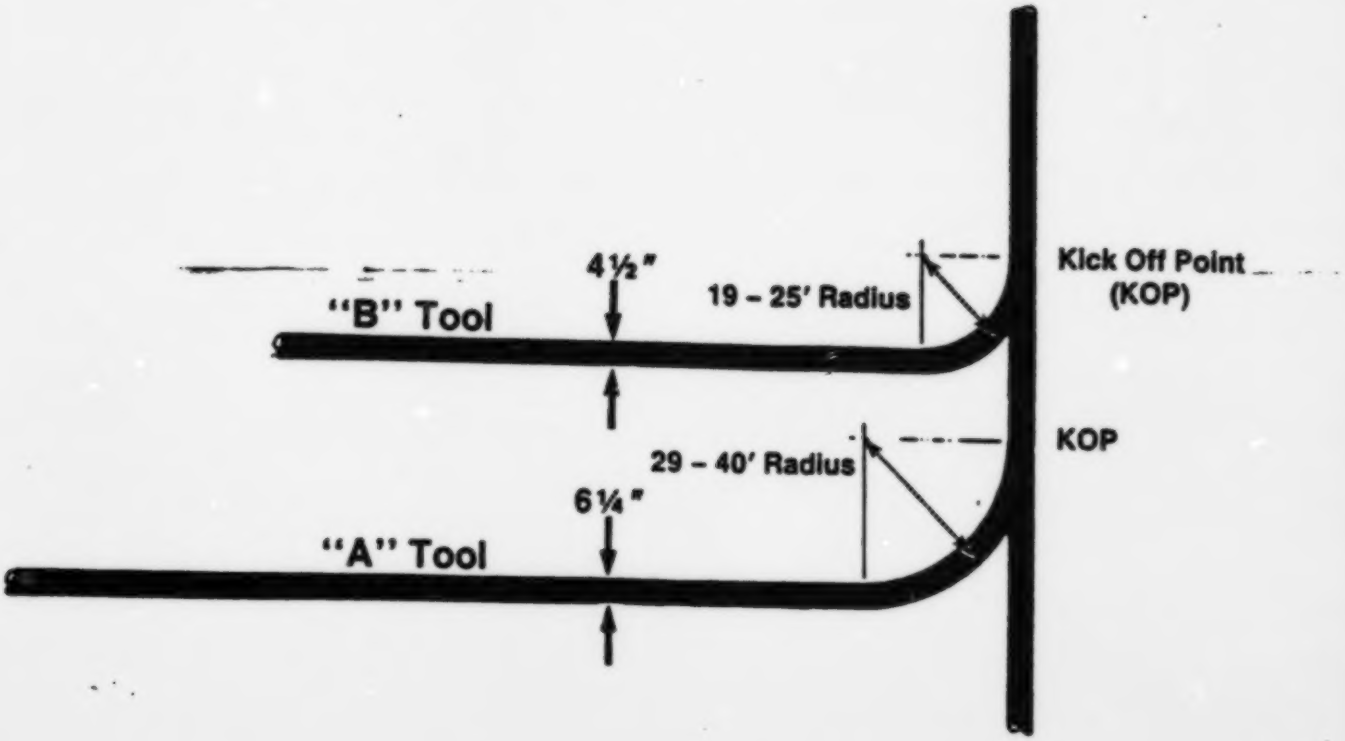
ACTUAL COMPLETION


0.03° TO 0.05°
PER FOOT
4,000'
5,900'
6,000'
1,000'
2,000'
CONVENTIONAL DIRECTIONAL DRILLING
1.5° TO 3.0°
PER FOOT
20' TO 40'
1,000'
TEDSI

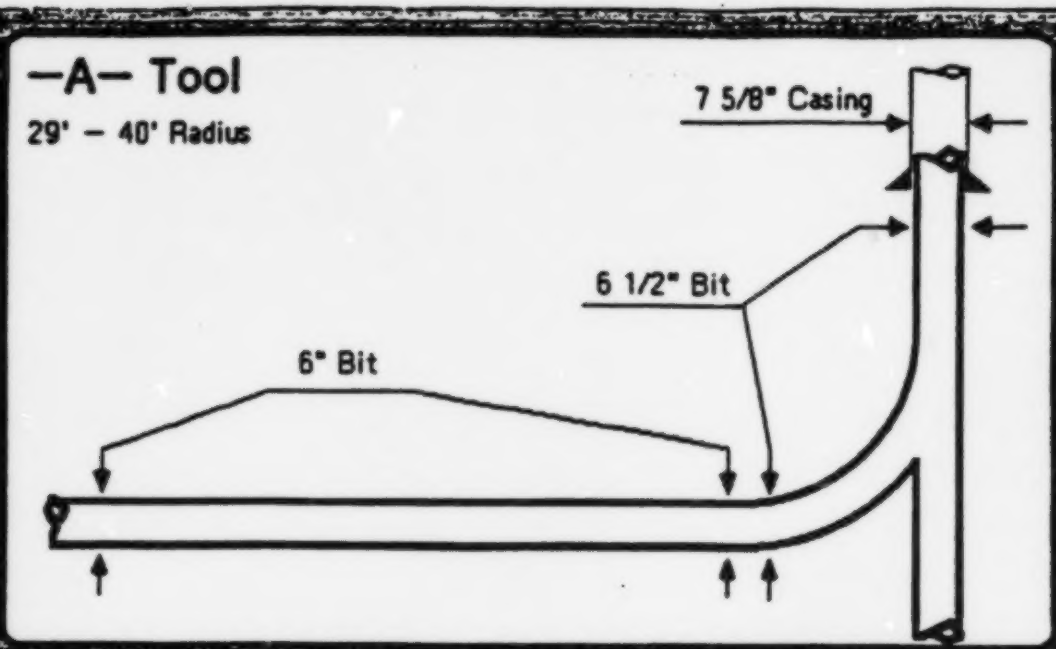
COMPARISON COMPLETION


CONVENTIONAL
TEDSI
18 FT$_2$ OF DRAINAGE SURFACE PER ZONE
1,800 FT$_2$ OF DRAINAGE SURFACE PER ZONE
7,500'
10'
500' (TYP.)
500' (TYP.)
10,000'
10'

THIN STRINGER COMPLETION COMPARISON

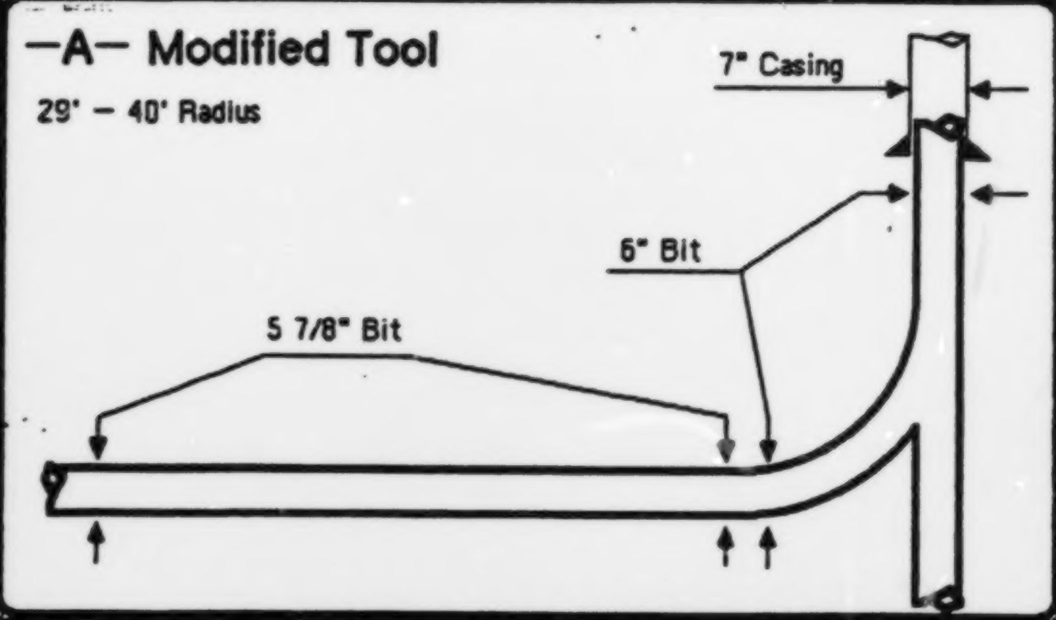

4½"
"B" Tool
19 – 25′ Radius
Kick Off Point
(KOP)
KOP
29 – 40′ Radius
6¼"
"A" Tool

LATERAL CHARACTERISTIC


—A— Tool

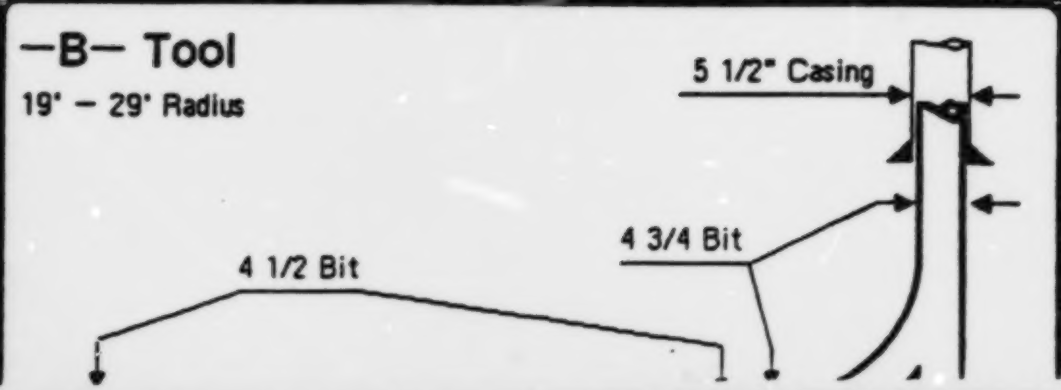
29' – 40' Radius

7 5/8" Casing
6 1/2" Bit
6" Bit


—A— Modified Tool

29' – 40' Radius

7" Casing
6" Bit
5 7/8" Bit

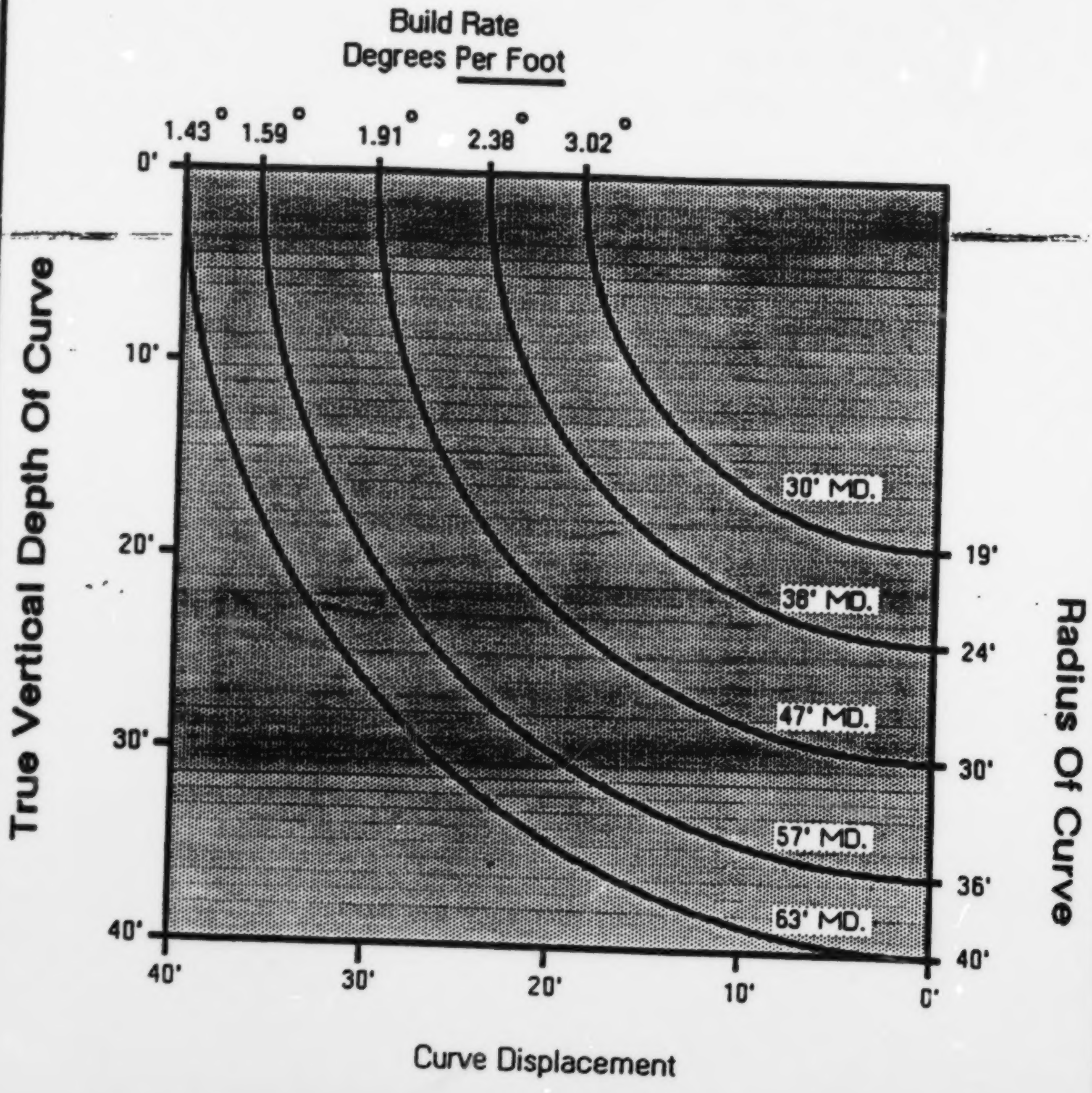

—B— Tool

19' – 29' Radius

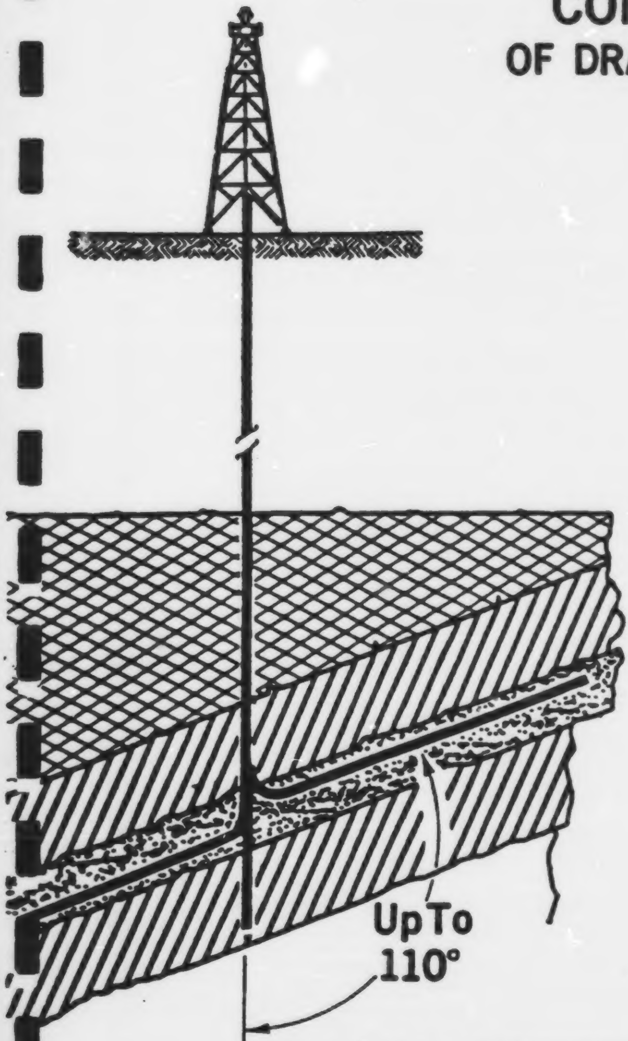
5 1/2" Casing
4 3/4 Bit
4 1/2 Bit

18

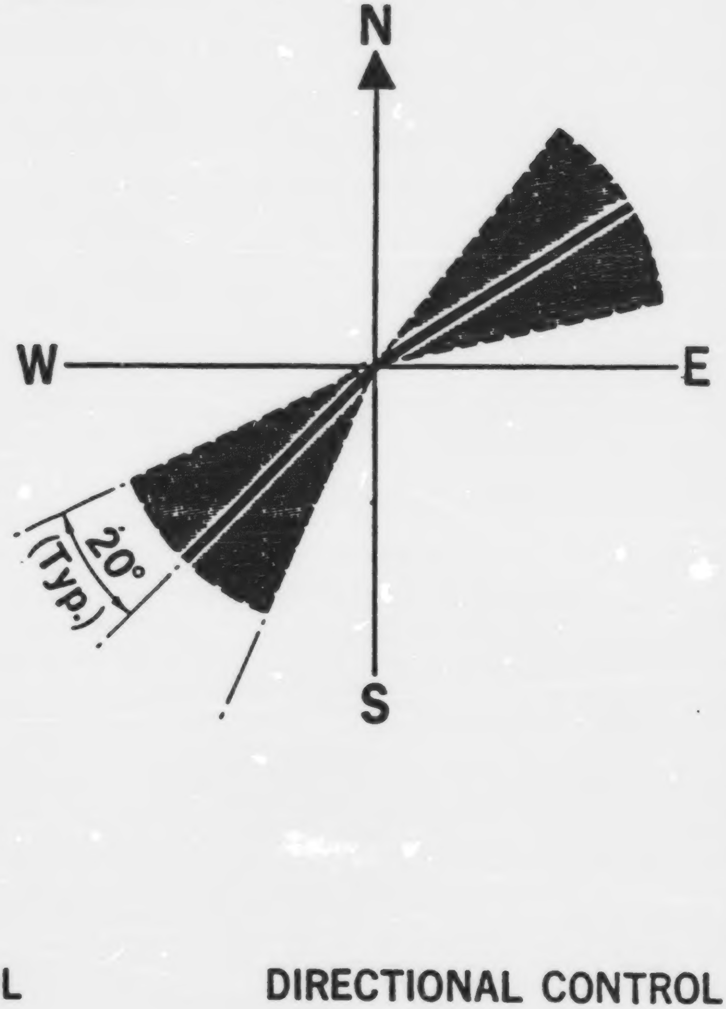
Lateral Completion Technique
Build—up Curve



CONTROL
OF DRAINHOLES

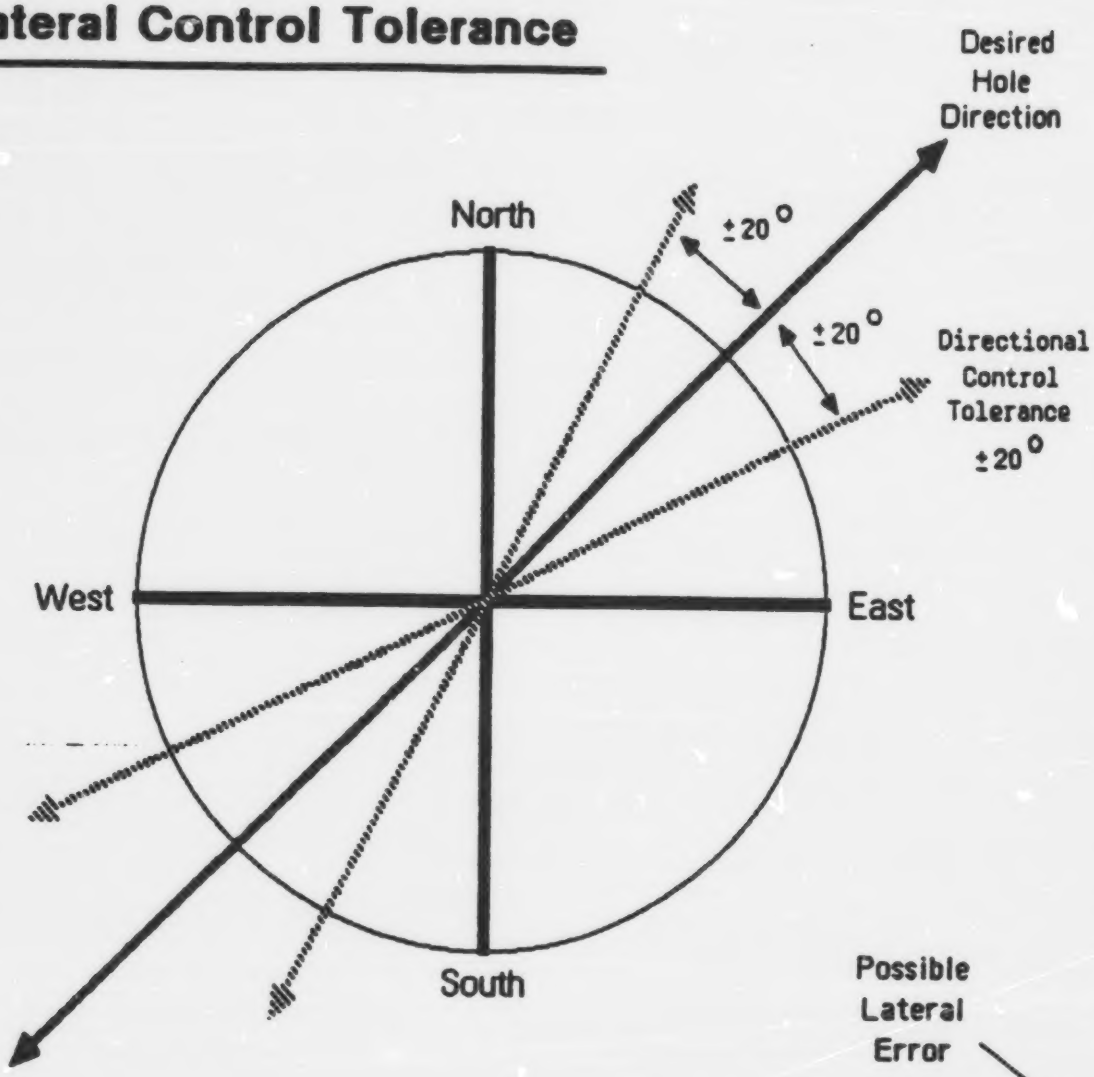


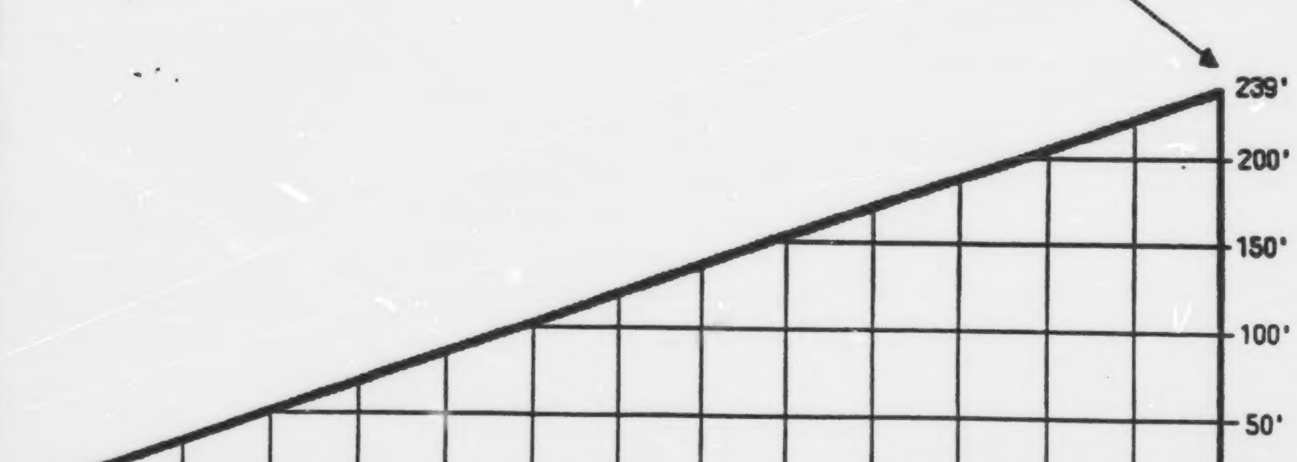
INCLINATION CONTROL



DIRECTIONAL CONTROL

Lateral Control Tolerance

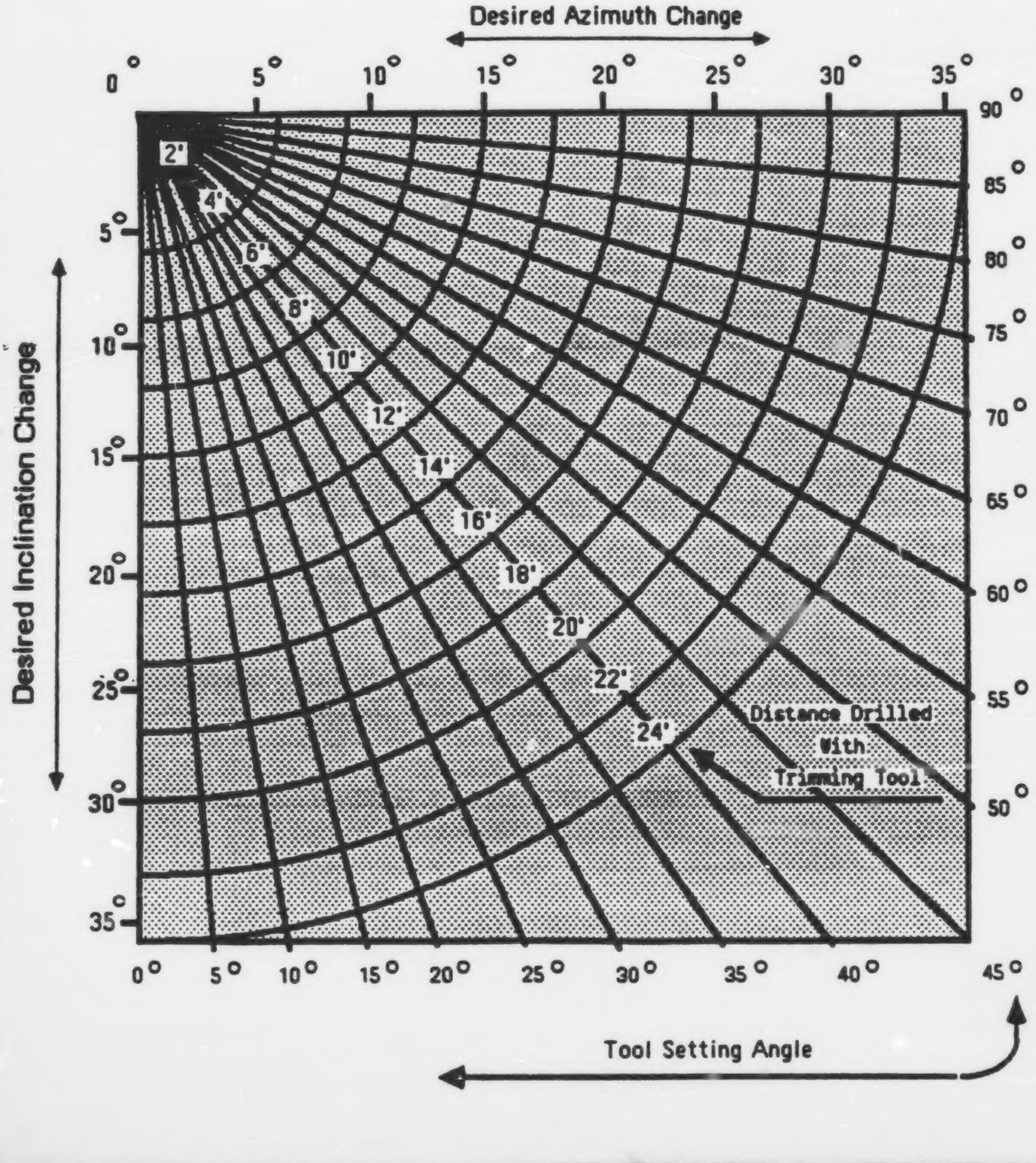

Desired
Hole
Direction
North
±20°
±20°
Directional
Control
Tolerance
±20°
West
East
South



21.

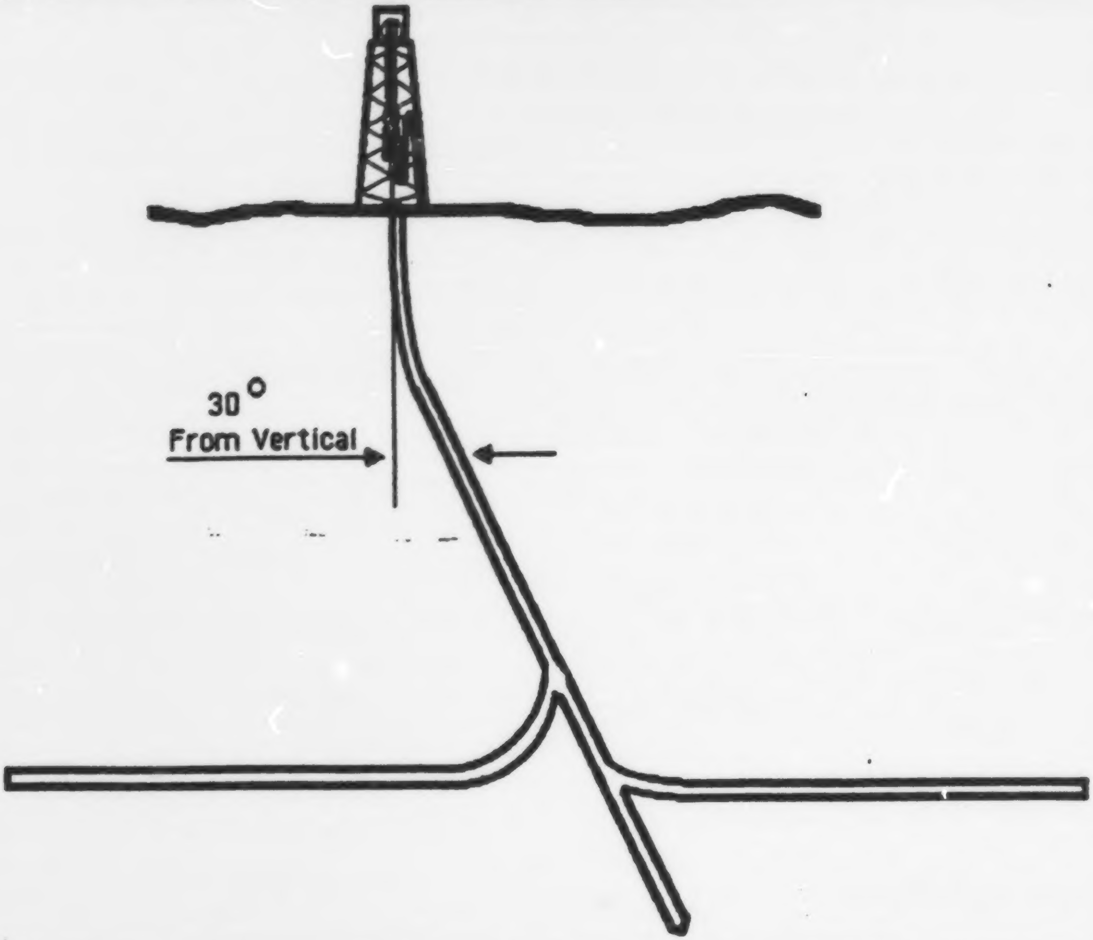
Lateral Direction Control Flexibility

(Trimming Tool)

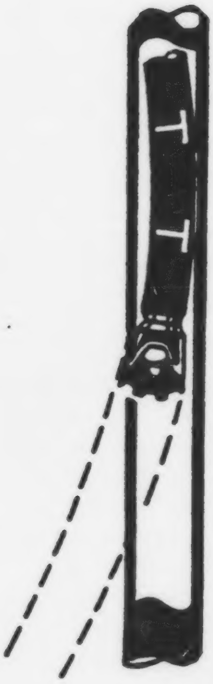


22.

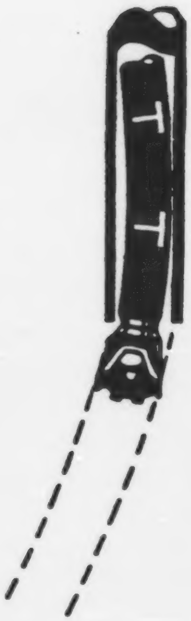
LCT from Conventional Directional Wells or from Existing Vertical Wells (Re—Entry)



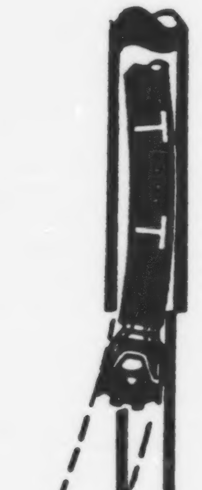
- Compatible with conventional rotary rigs, drilling fluids and rig crews.
- Ability to work in new wells or re—enter existing wells.
- Ability to work from vertical or deviated wells.
- Working depths to date; up to 10,000 feet.
- Multiple laterals per well.



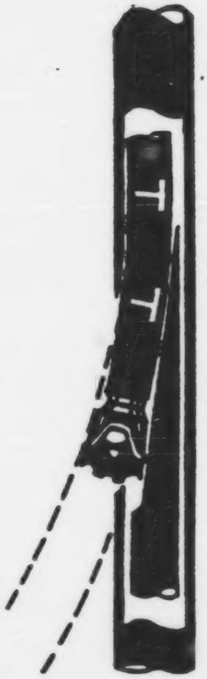
OPEN HOLE METHOD



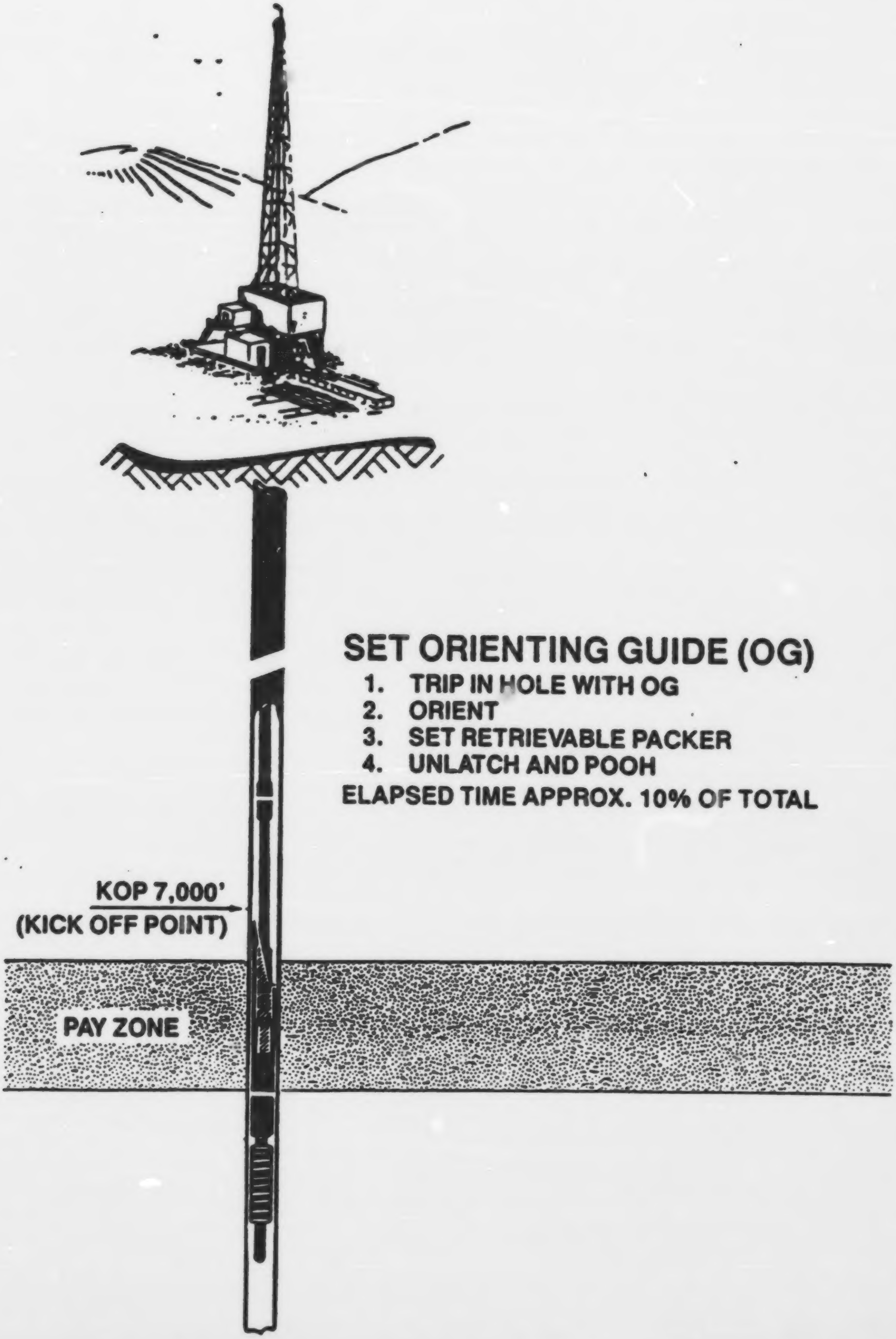
BOTTOM HOLE METHOD



LEDGE METHOD



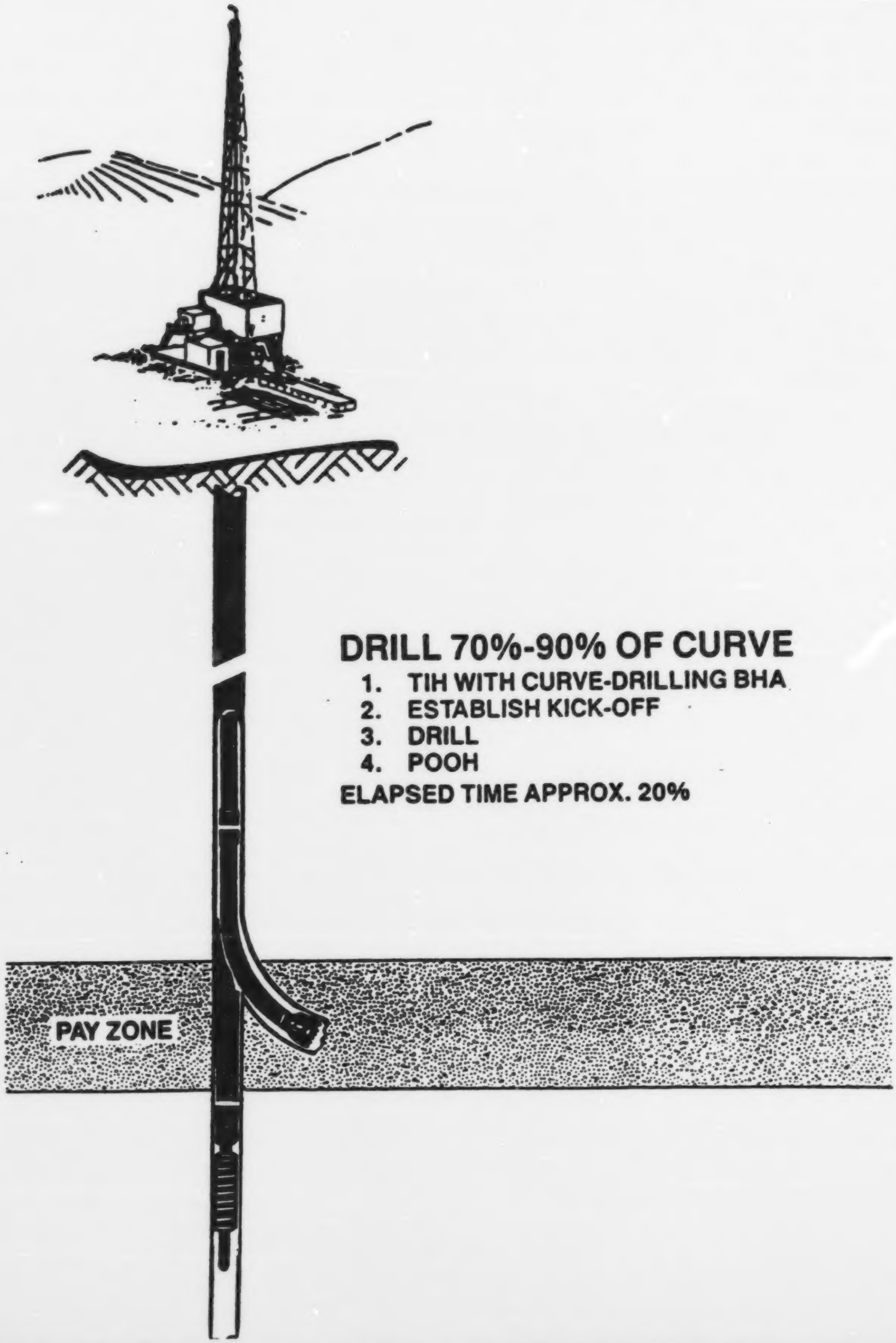
ORIENTATION GUIDE METHOD


KOP 7,000'
(KICK OFF POINT)
PAY ZONE

SET ORIENTING GUIDE (OG)

1. TRIP IN HOLE WITH OG
2. ORIENT
3. SET RETRIEVABLE PACKER
4. UNLATCH AND POOH

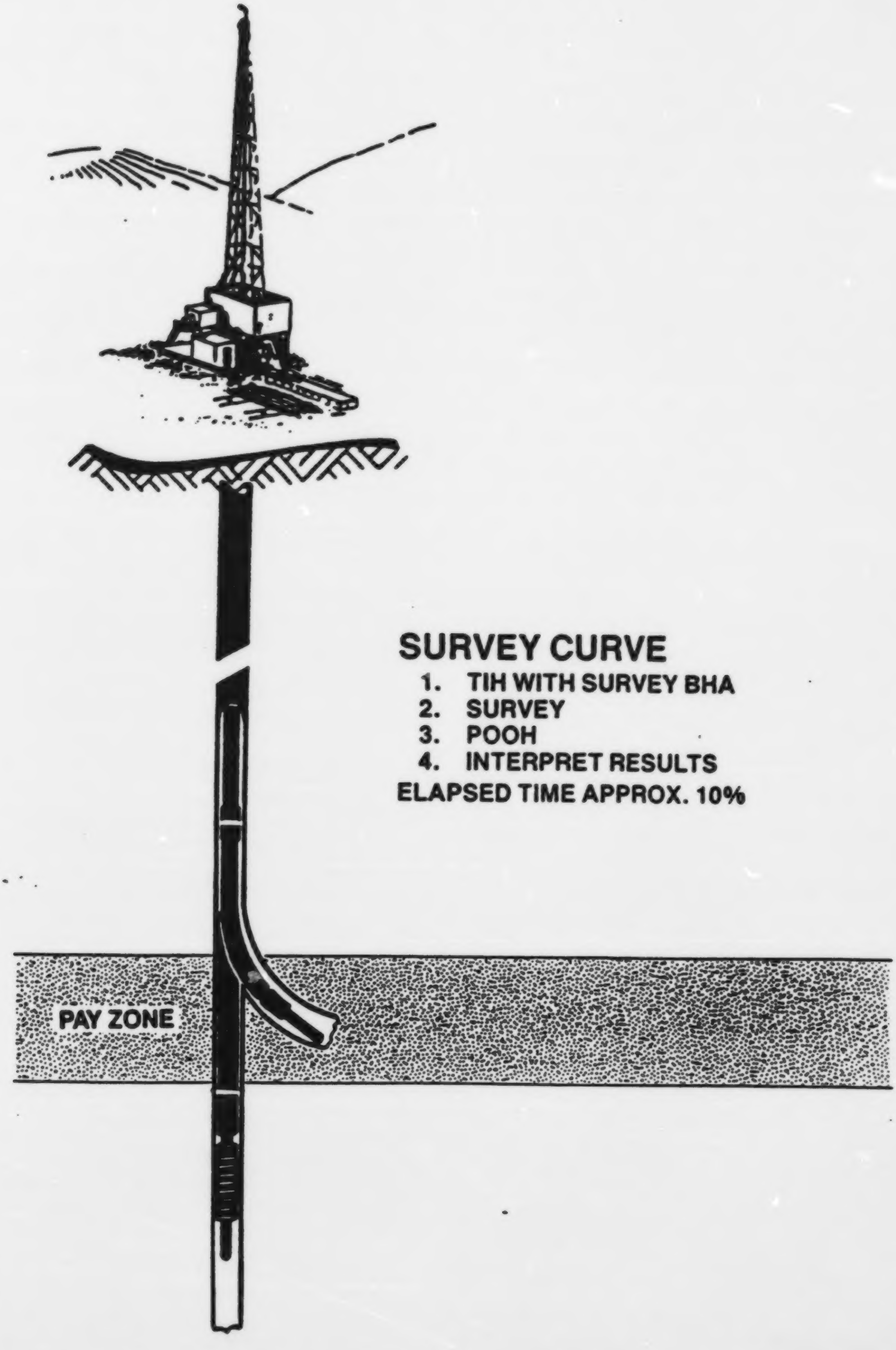
ELAPSED TIME APPROX. 10% OF TOTAL



DRILL 70%-90% OF CURVE

1. TIH WITH CURVE-DRILLING BHA
2. ESTABLISH KICK-OFF
3. DRILL
4. POOH

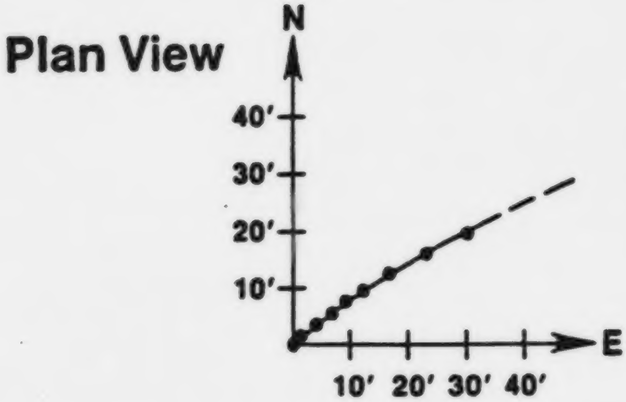
ELAPSED TIME APPROX. 20%

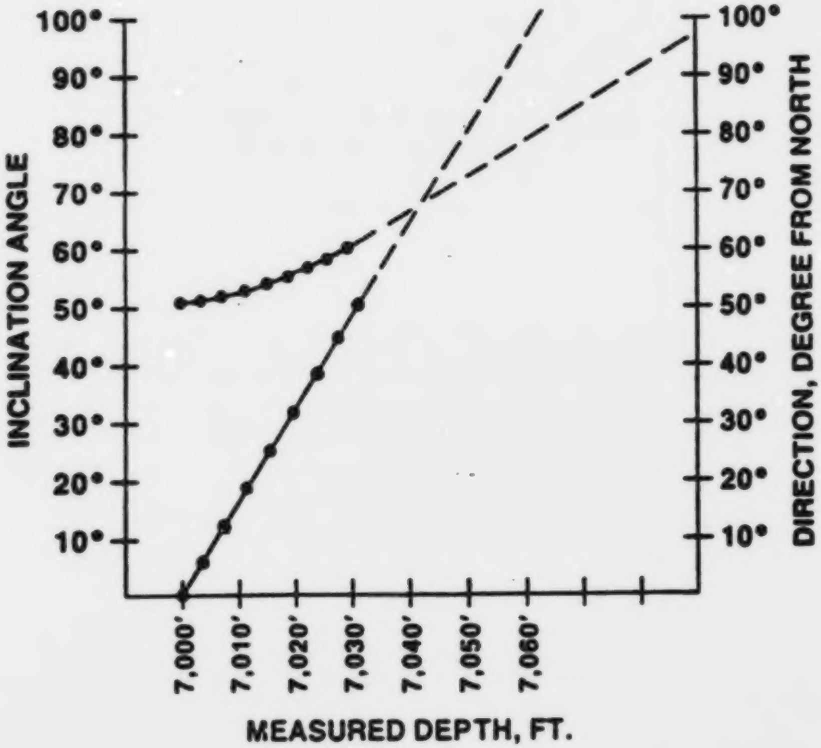


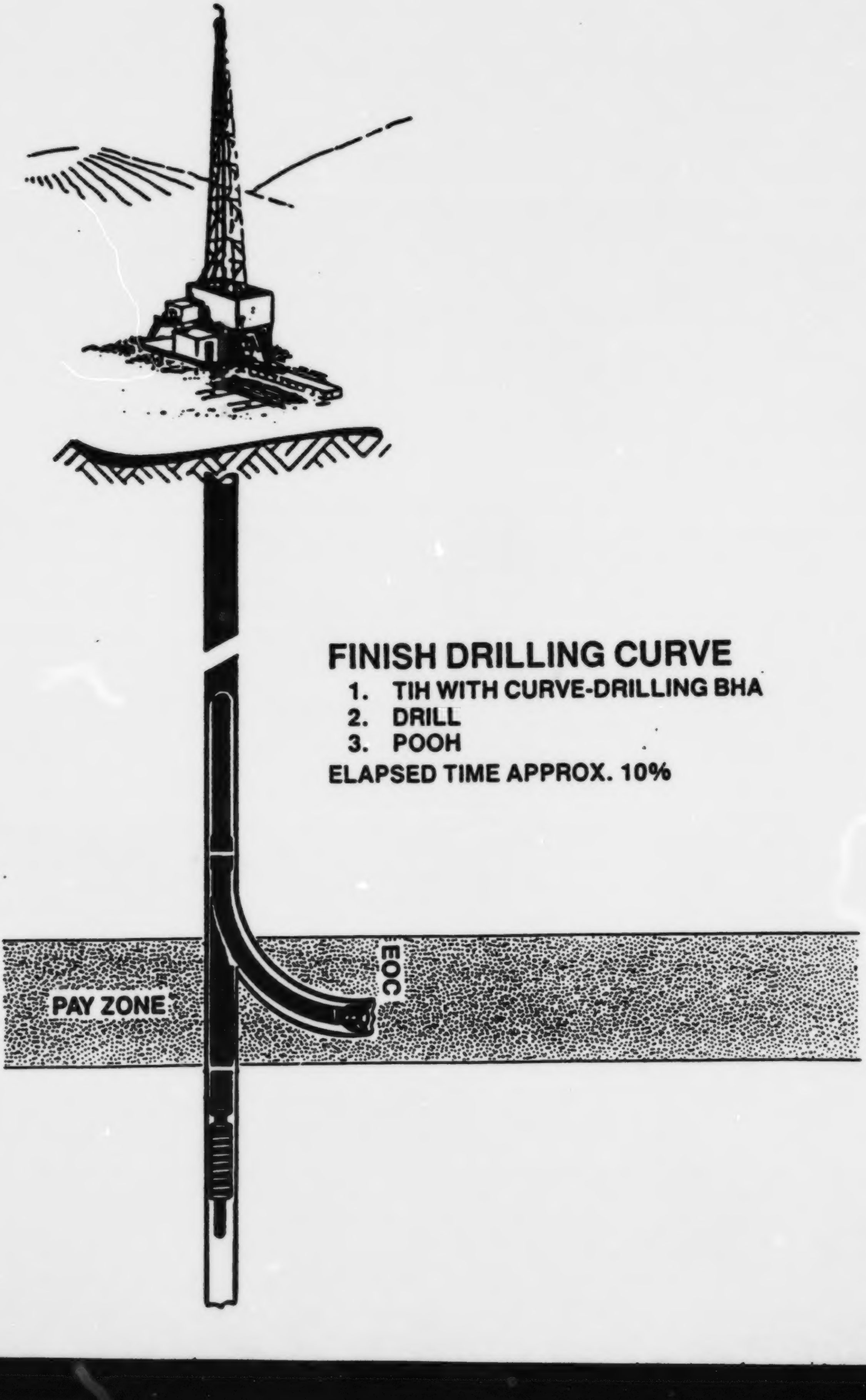
SURVEY CURVE

1. TIH WITH SURVEY BHA
2. SURVEY
3. POOH
4. INTERPRET RESULTS

ELAPSED TIME APPROX. 10%


Plan View
N
40'
30'
20'
10'
E
10'
20'
30'
40'

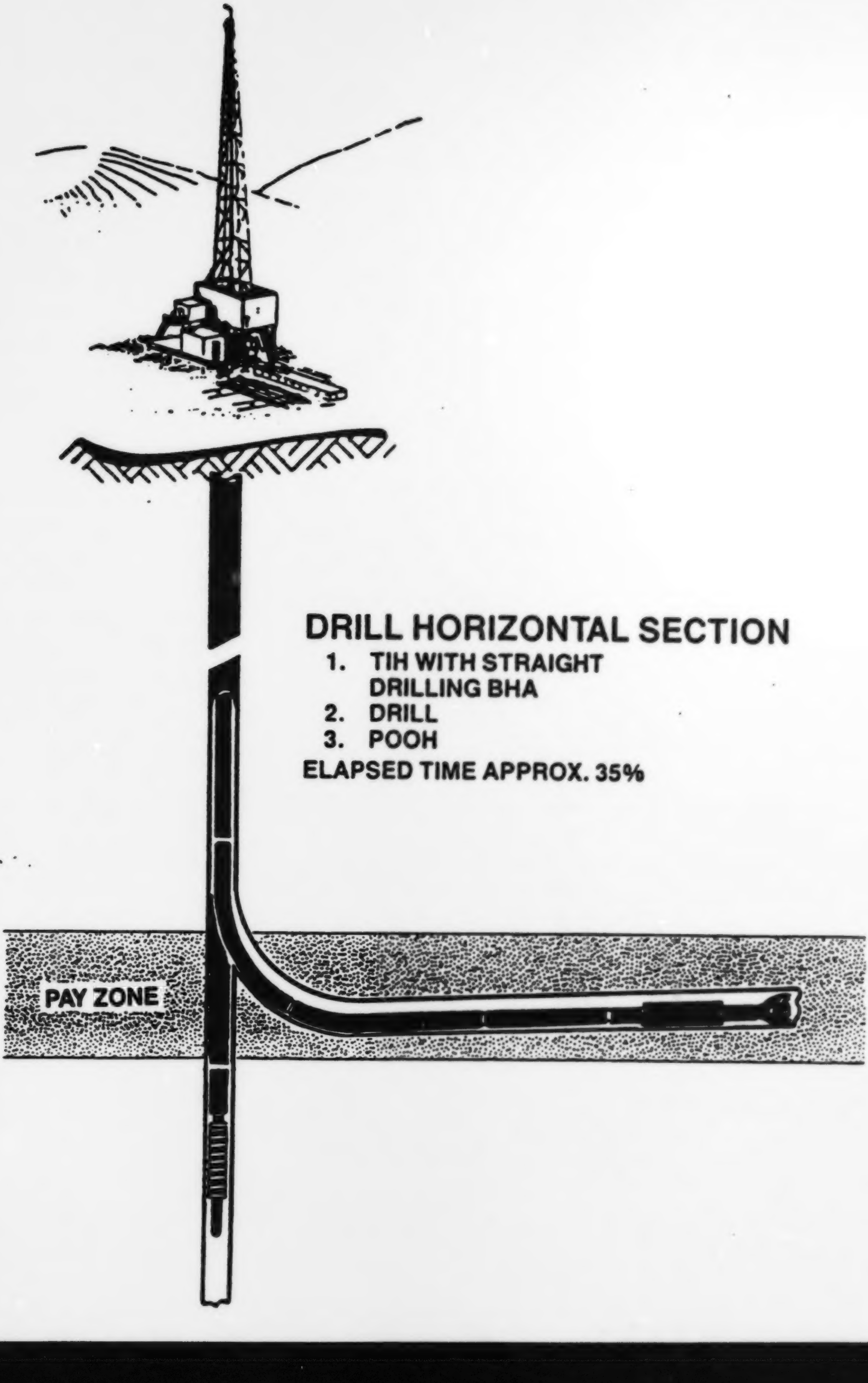

100°
90°
80°
70°
60°
50°
40°
30°
20°
10°
INCLINATION ANGLE
100°
90°
80°
70°
60°
50°
40°
30°
20°
10°
DIRECTION, DEGREE FROM NORTH
7,000'
7,010'
7,020'
7,030'
7,040'
7,050'
7,060'
MEASURED DEPTH, FT.


PAY ZONE
EOC

FINISH DRILLING CURVE

1. TIH WITH CURVE-DRILLING BHA
2. DRILL
3. POOH

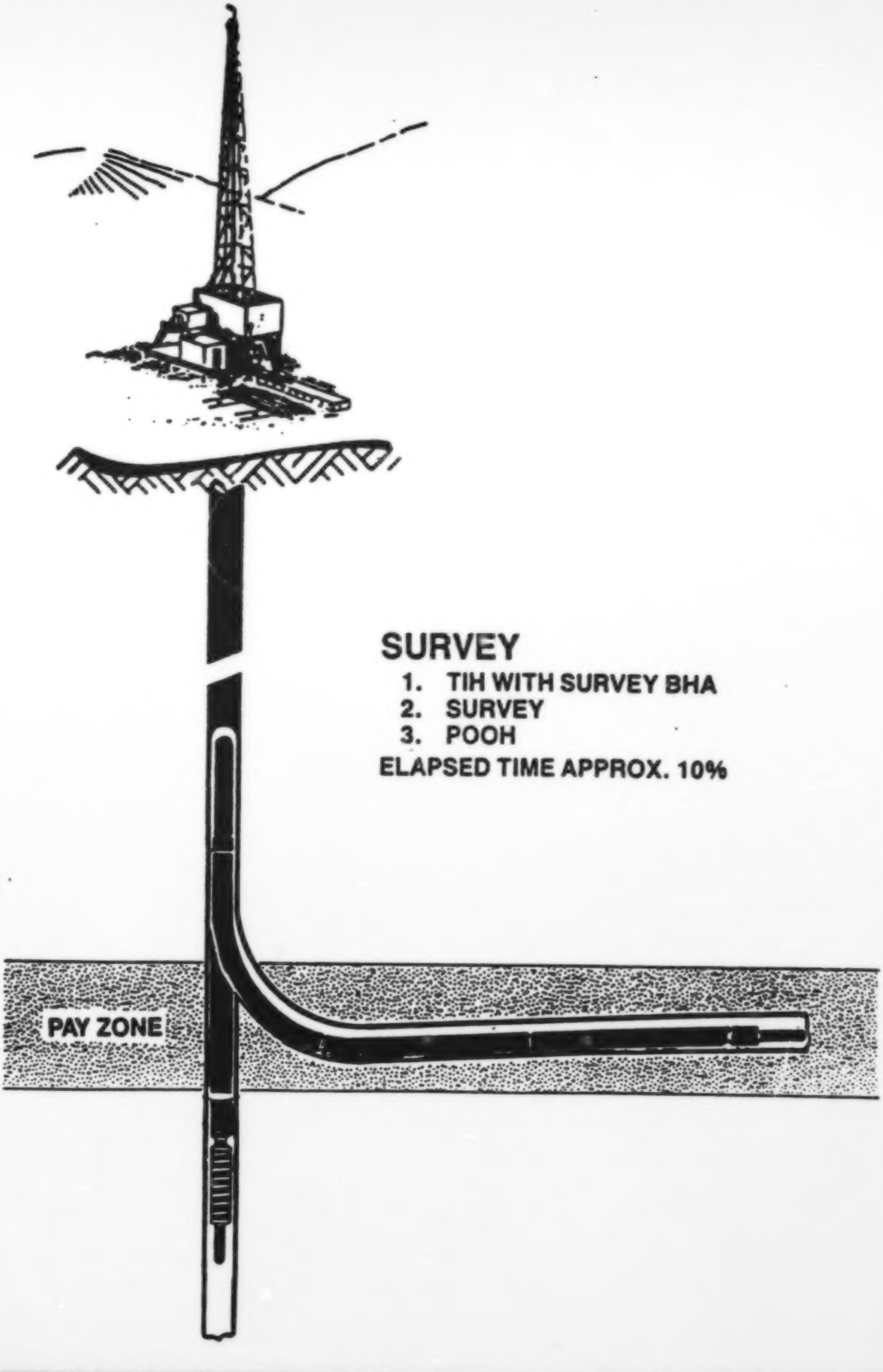
ELAPSED TIME APPROX. 10%



DRILL HORIZONTAL SECTION

1. TIH WITH STRAIGHT DRILLING BHA
2. DRILL
3. POOH

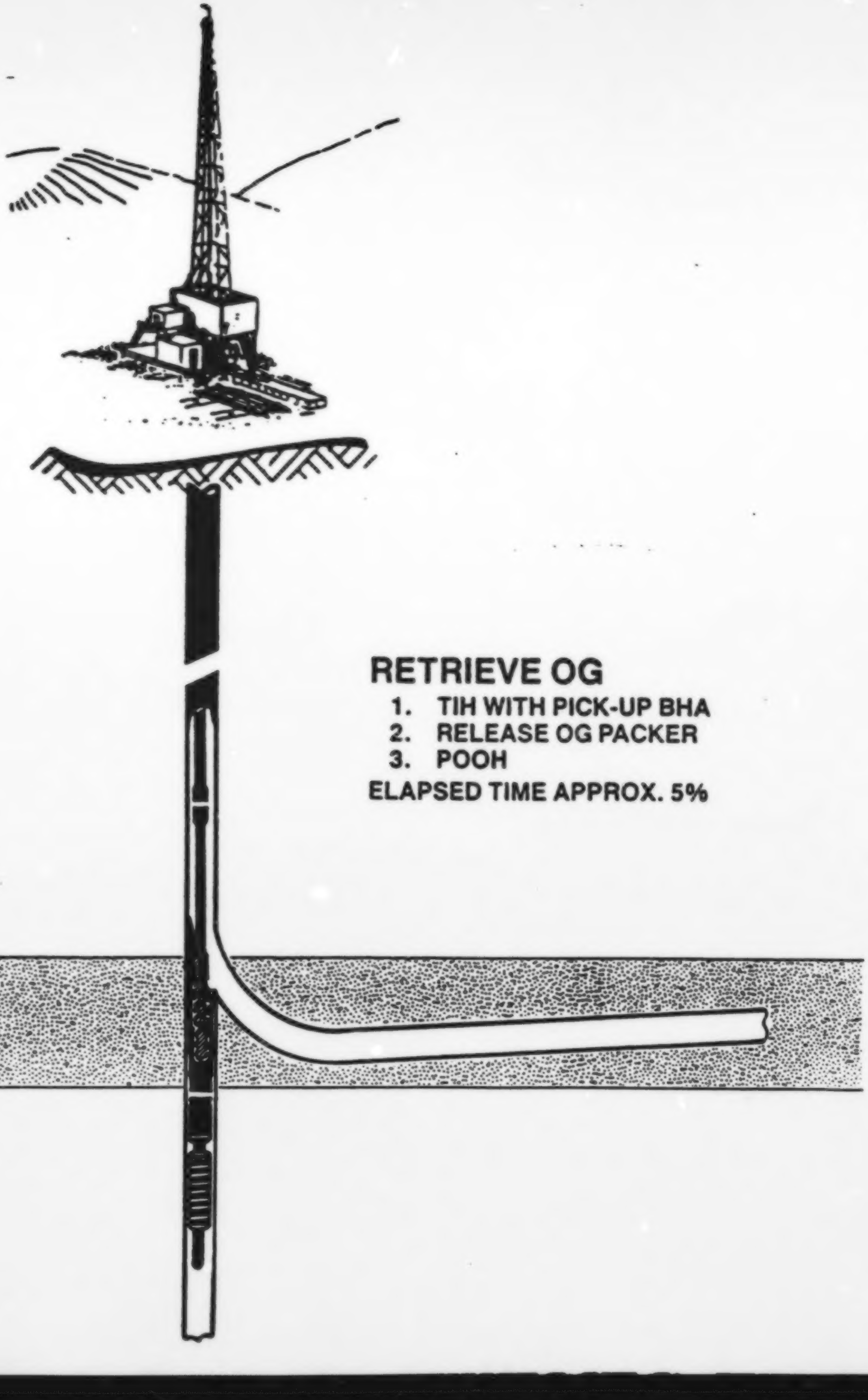
ELAPSED TIME APPROX. 35%



SURVEY

1. TIH WITH SURVEY BHA
2. SURVEY
3. POOH

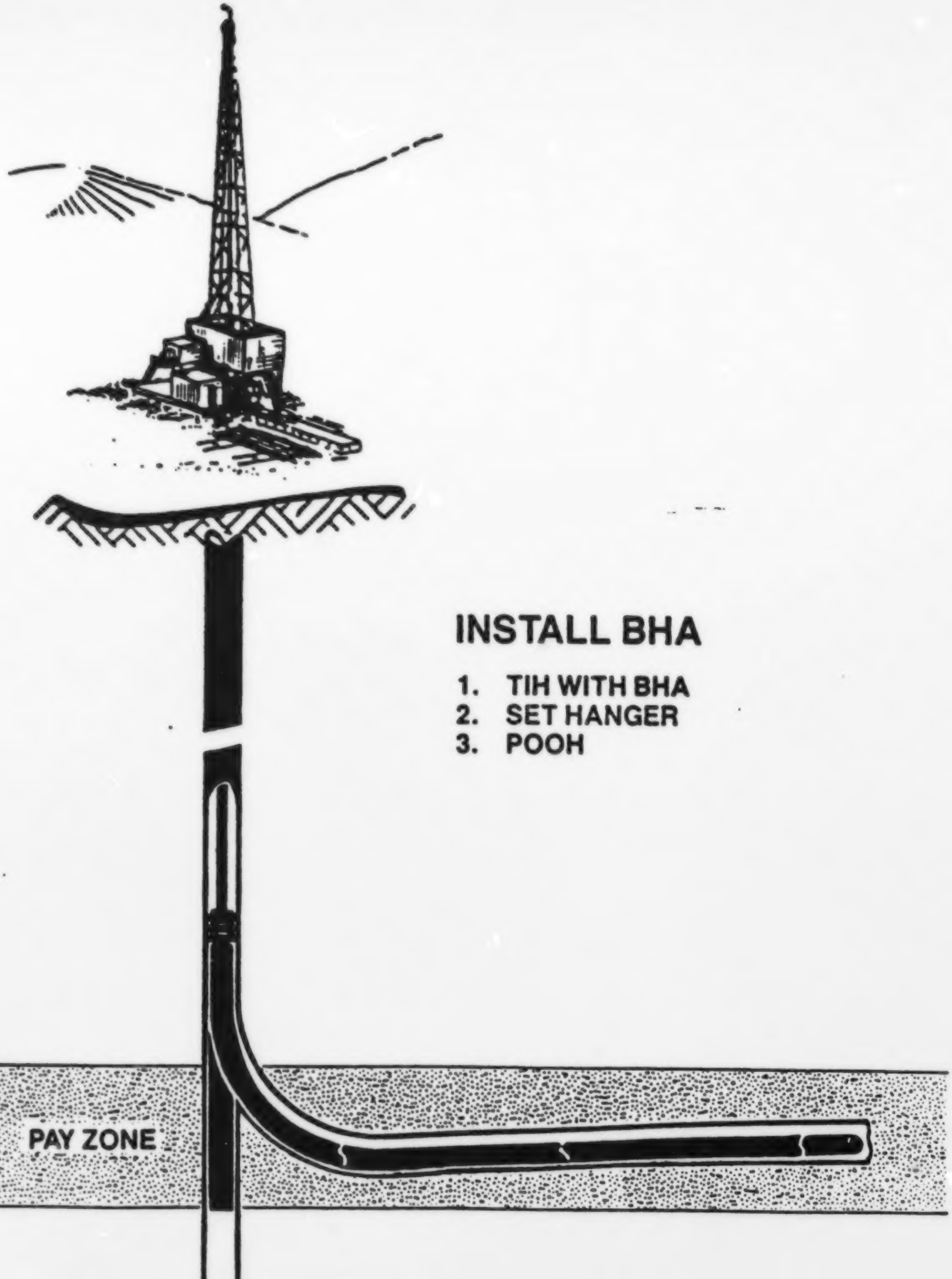
ELAPSED TIME APPROX. 10%



RETRIEVE OG

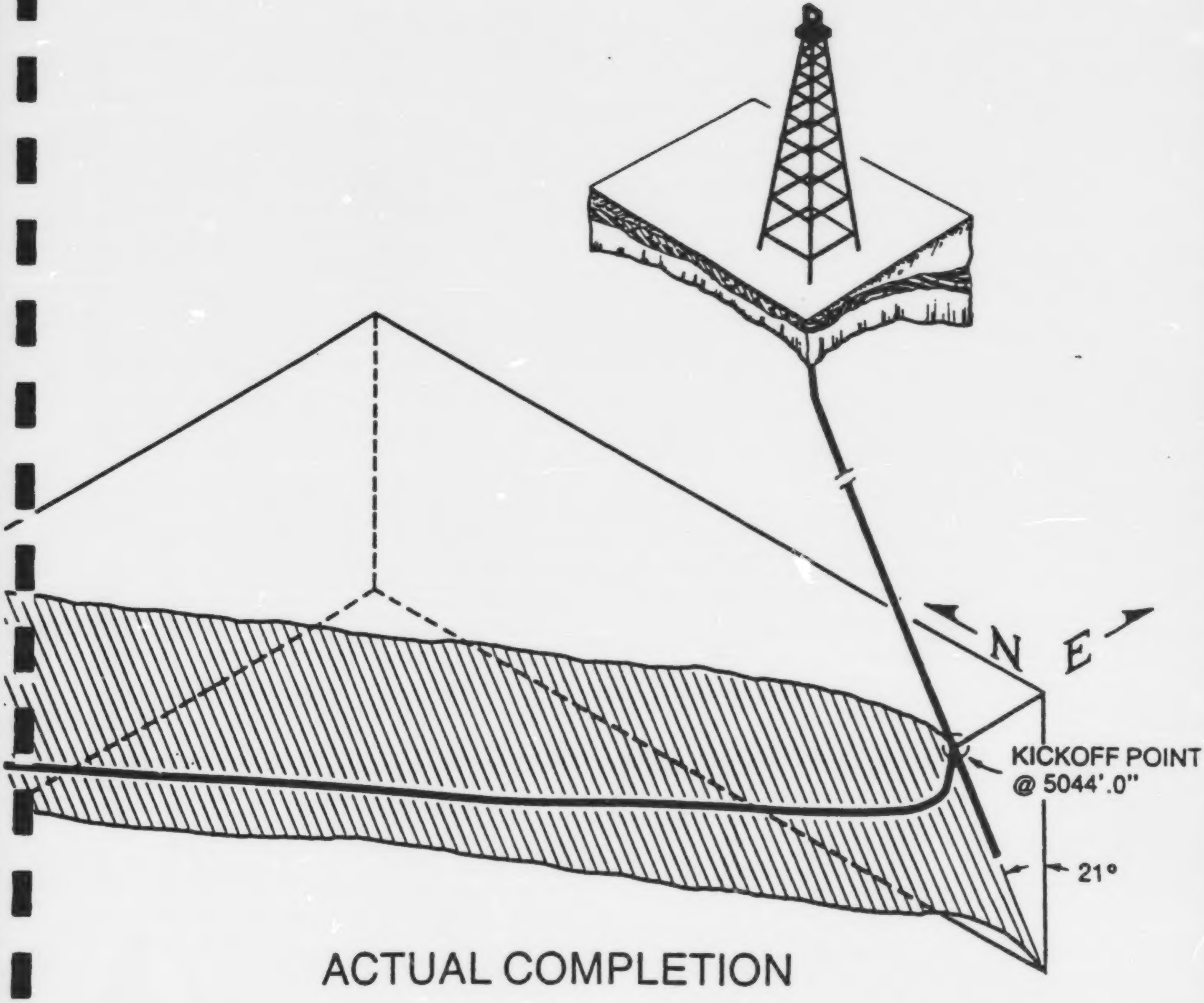
1. TIH WITH PICK-UP BHA
2. RELEASE OG PACKER
3. POOH

ELAPSED TIME APPROX. 5%

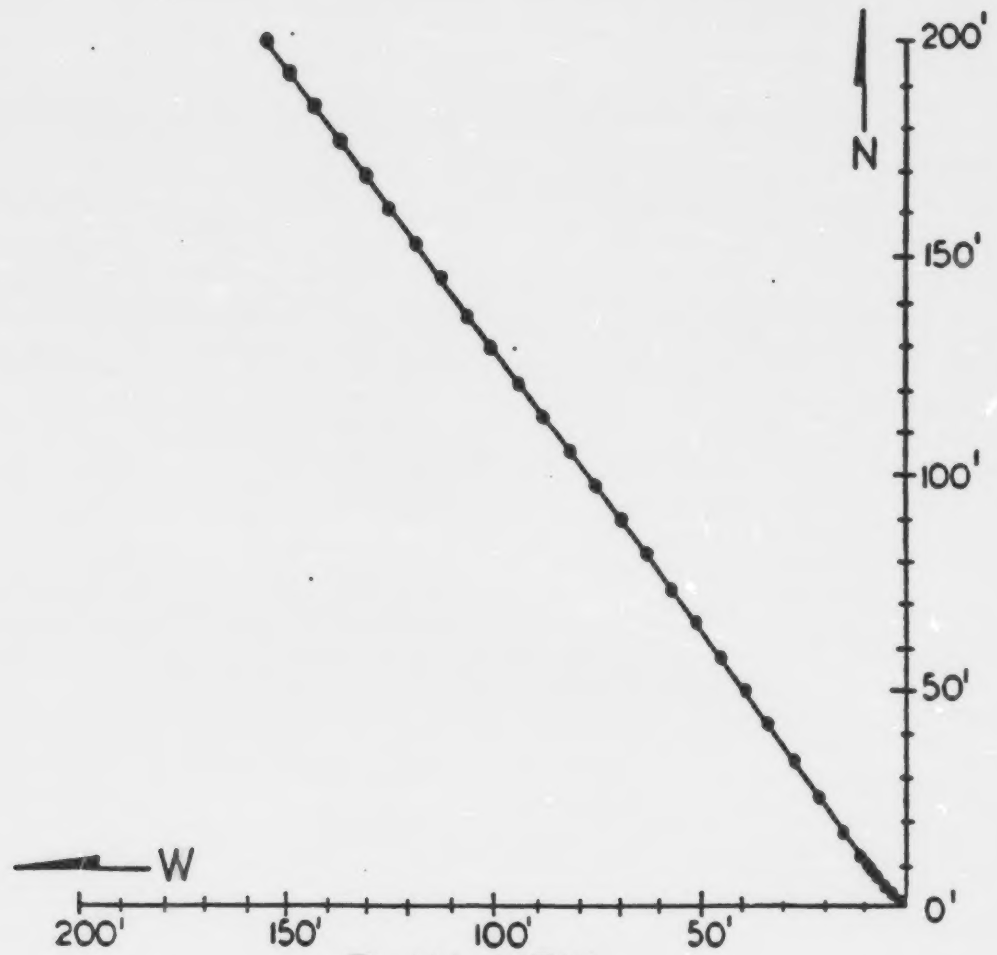


INSTALL BHA

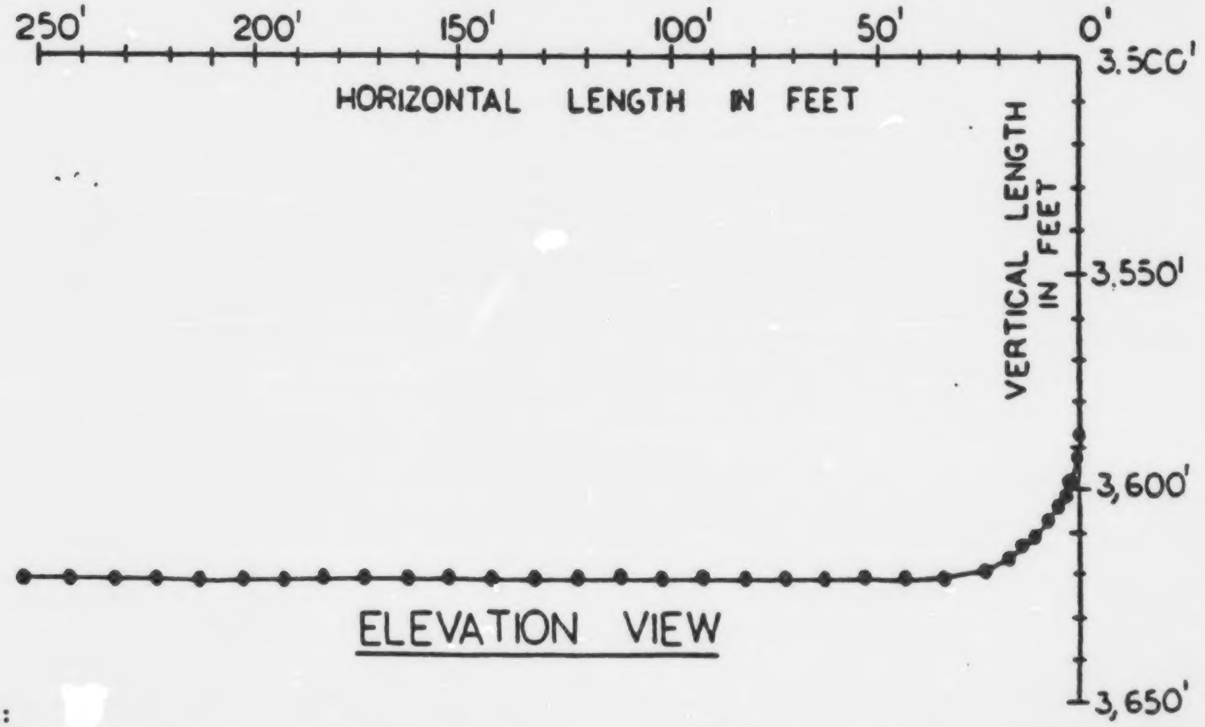
1. TIH WITH BHA
2. SET HANGER
3. POOH


N
E
KICKOFF POINT
@ 5044'.0"
21°

ACTUAL COMPLETION



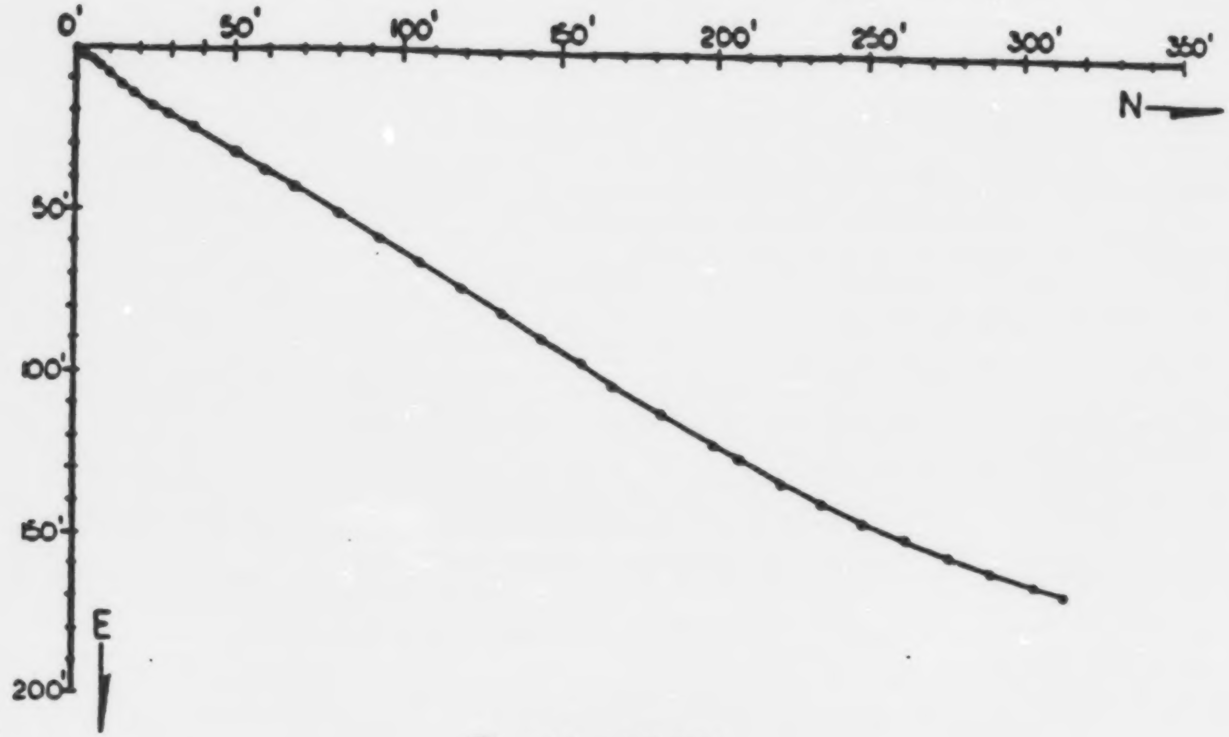
PLAN VIEW



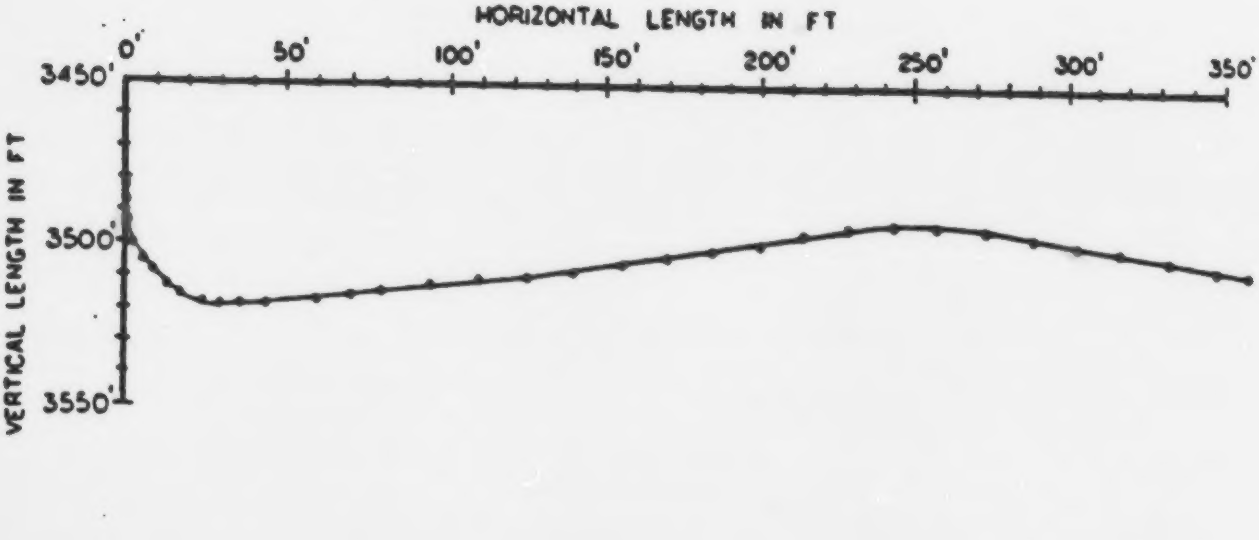
ELEVATION VIEW

TITLE:

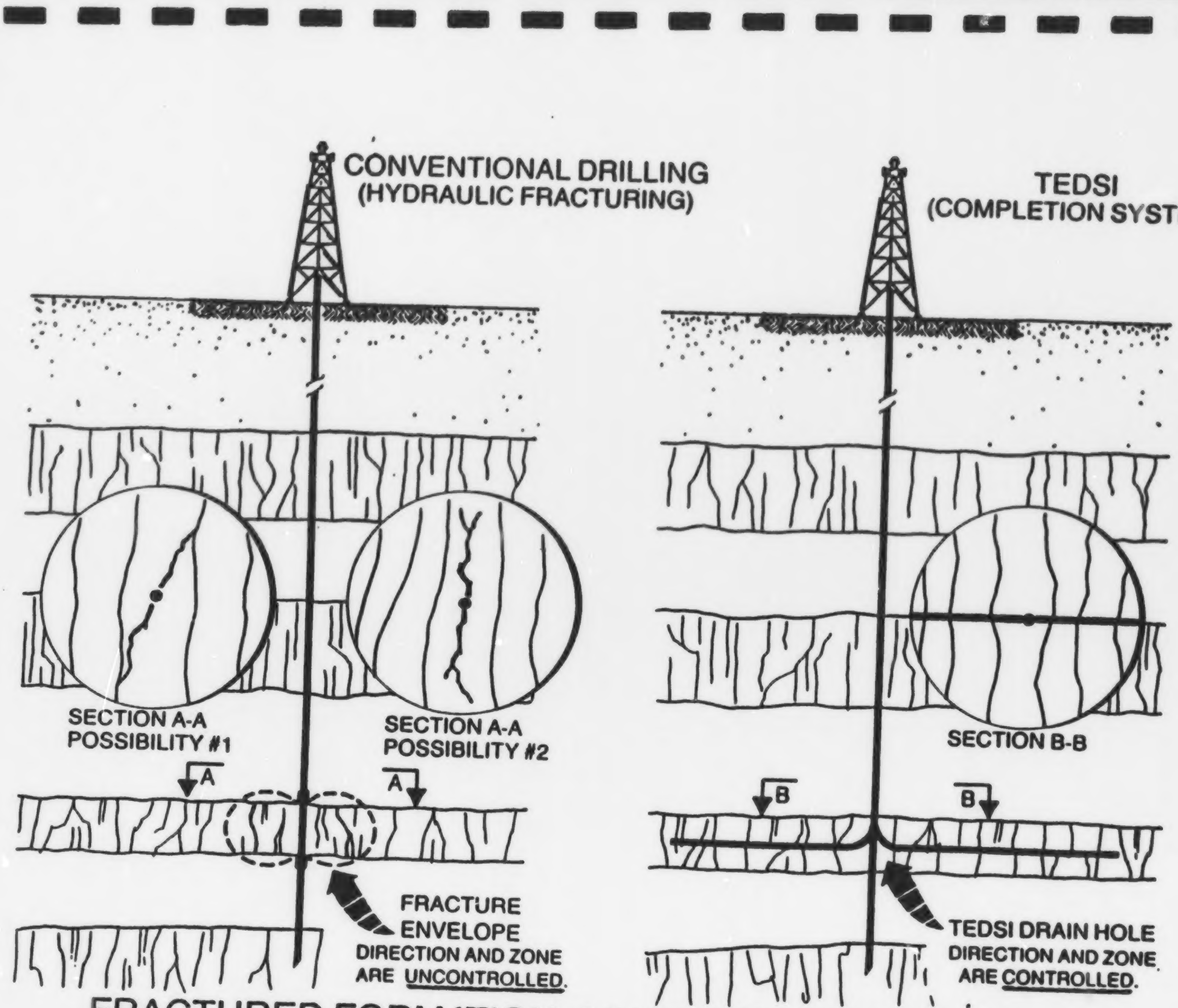
TERSL DRAINHOLE PLOTTED FROM ACTUAL FIELD SURVEY



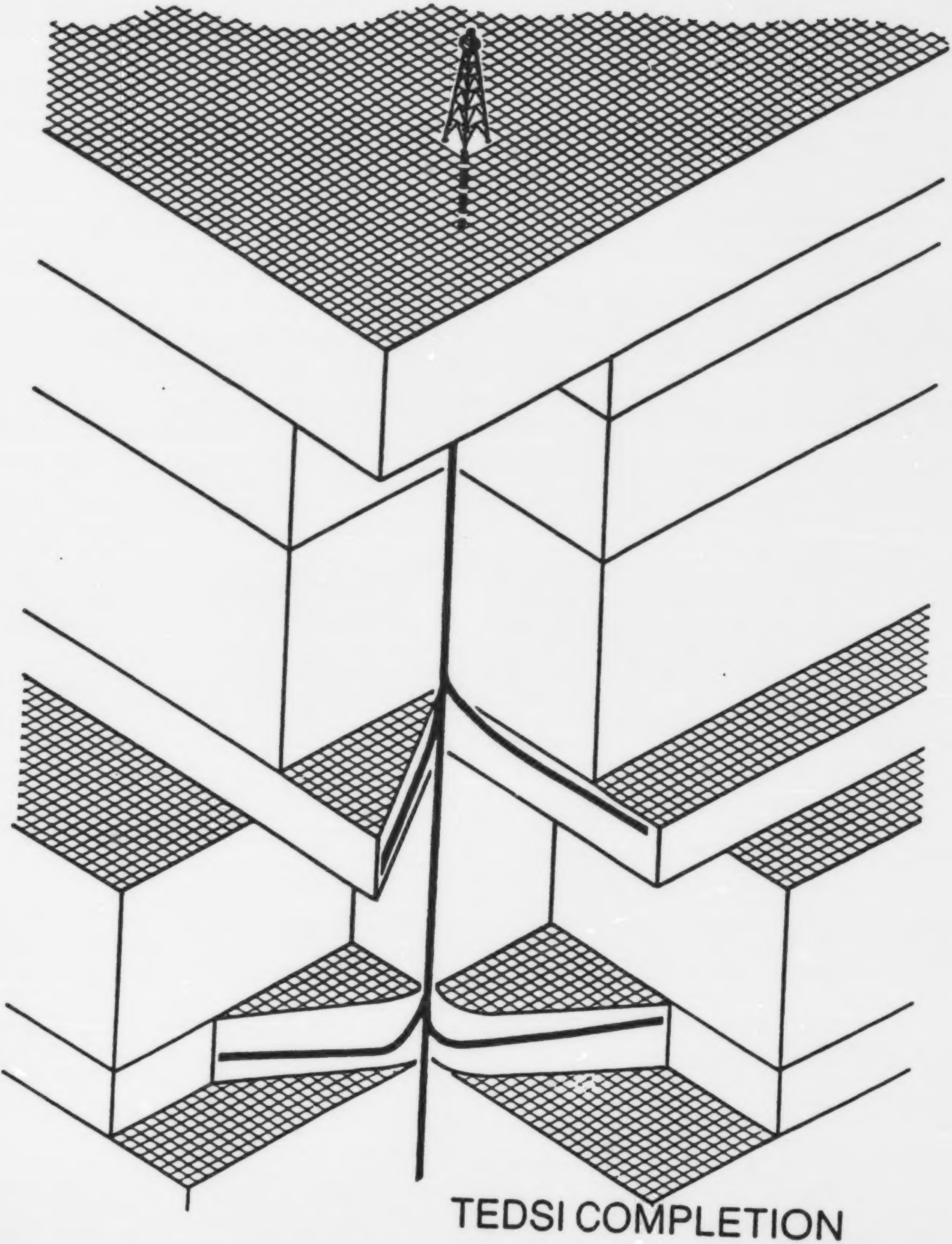
PLAN VIEW



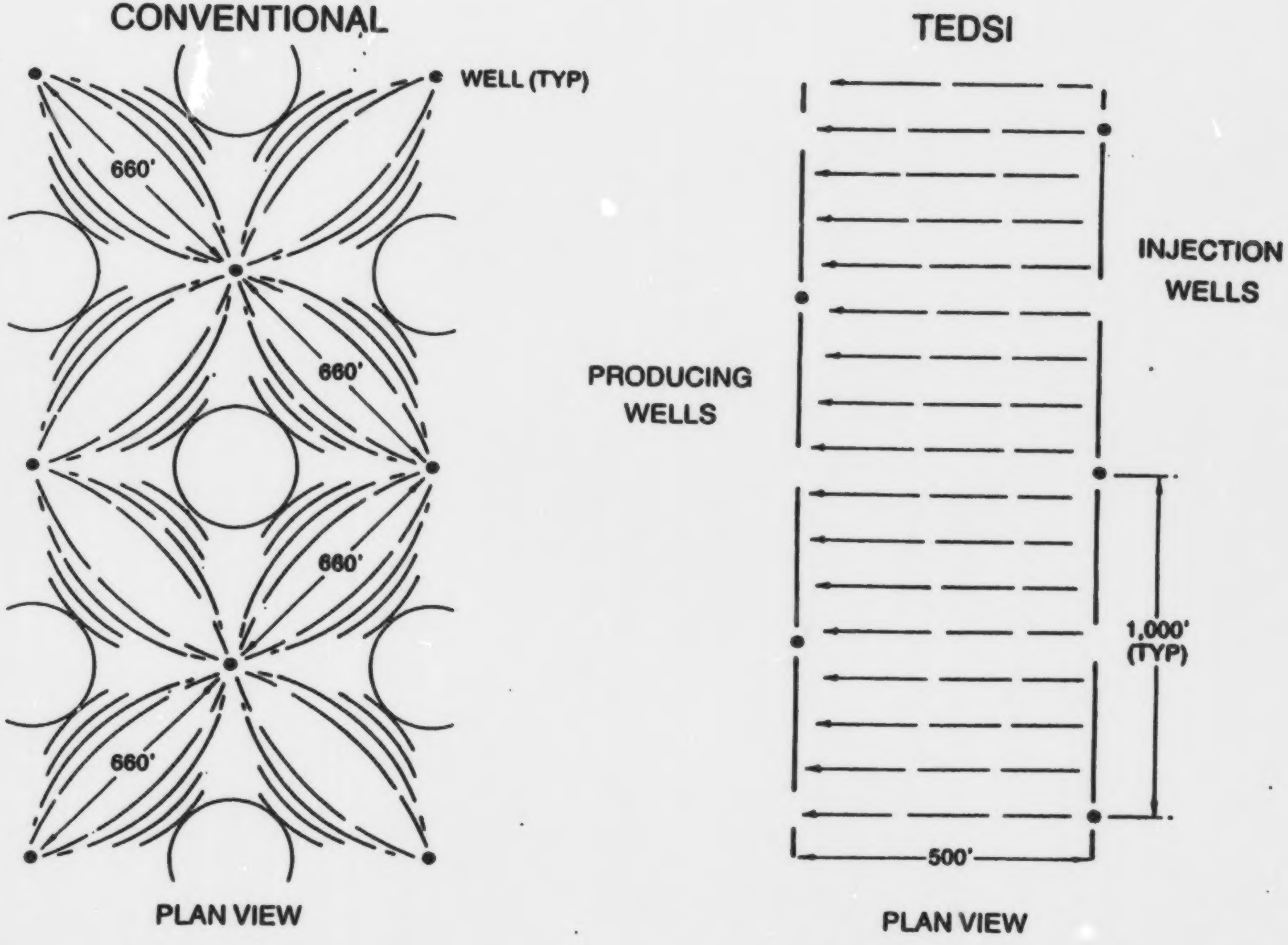
ELEVATION VIEW


CONVENTIONAL DRILLING
(HYDRAULIC FRACTURING)
TEDSI
(COMPLETION SYSTEM)
SECTION A-A
POSSIBILITY #1
SECTION A-A
POSSIBILITY #2
SECTION B-B
A
A
B
B
FRACTURE
ENVELOPE
DIRECTION AND ZONE
ARE UNCONTROLLED.
TEDSI DRAIN HOLE
DIRECTION AND ZONE
ARE CONTROLLED.

FRACTURED FORMATION COMPLETION COMPARISON

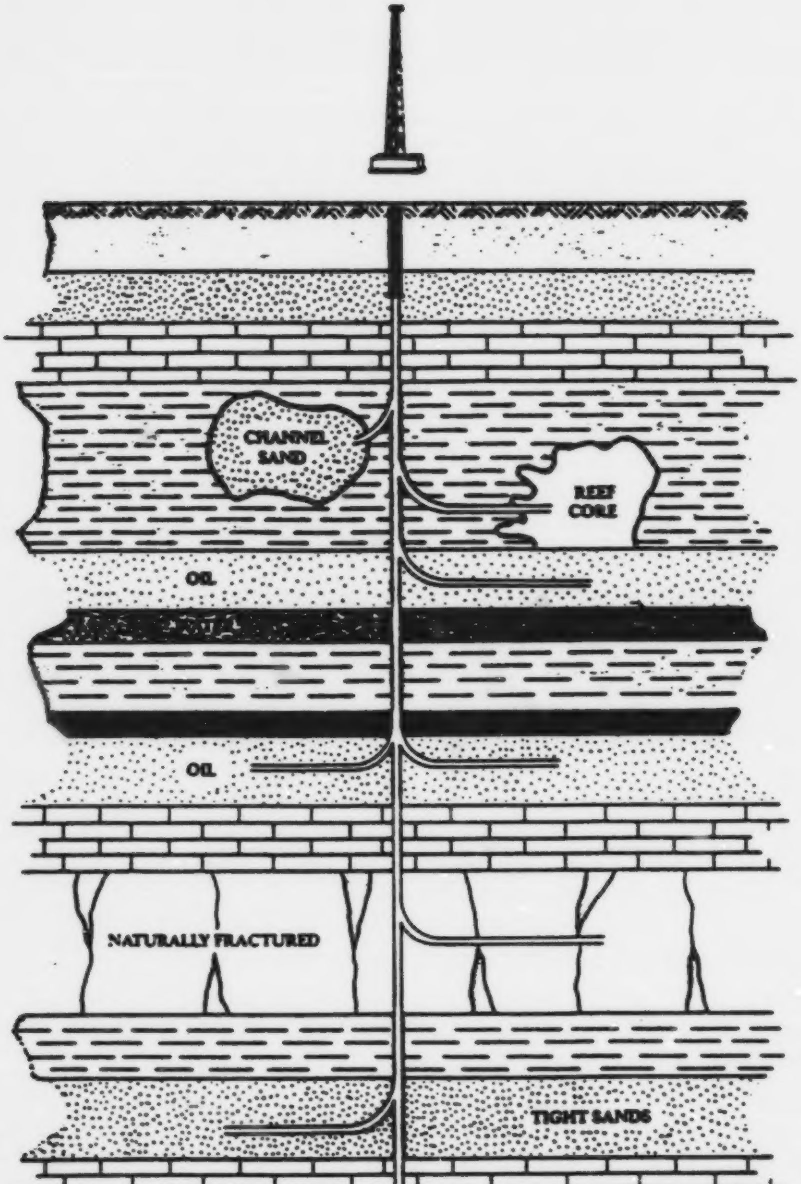


TEDSI COMPLETION


CONVENTIONAL
WELL (TYP)
660'
660'
660'
660'
PLAN VIEW
TEDSI
INJECTION WELLS
PRODUCING WELLS
1,000' (TYP)
500'
PLAN VIEW

ENHANCED RECOVERY COMPARISON

A PROBLEM SOLVING COMPLETION TECHNOLOGY


CHANNEL SAND
REEF CORE
OIL
OIL
NATURALLY FRACTURED
TIGHT SANDS
LOW PRESSURE

Reach irregular reservoirs without additional wells

Limit invasion of unwanted formation fluids (coning)

Maximize recovery efficiency by conserving reservoir energy

Penetrate natural vertical fractures missed by wellbore

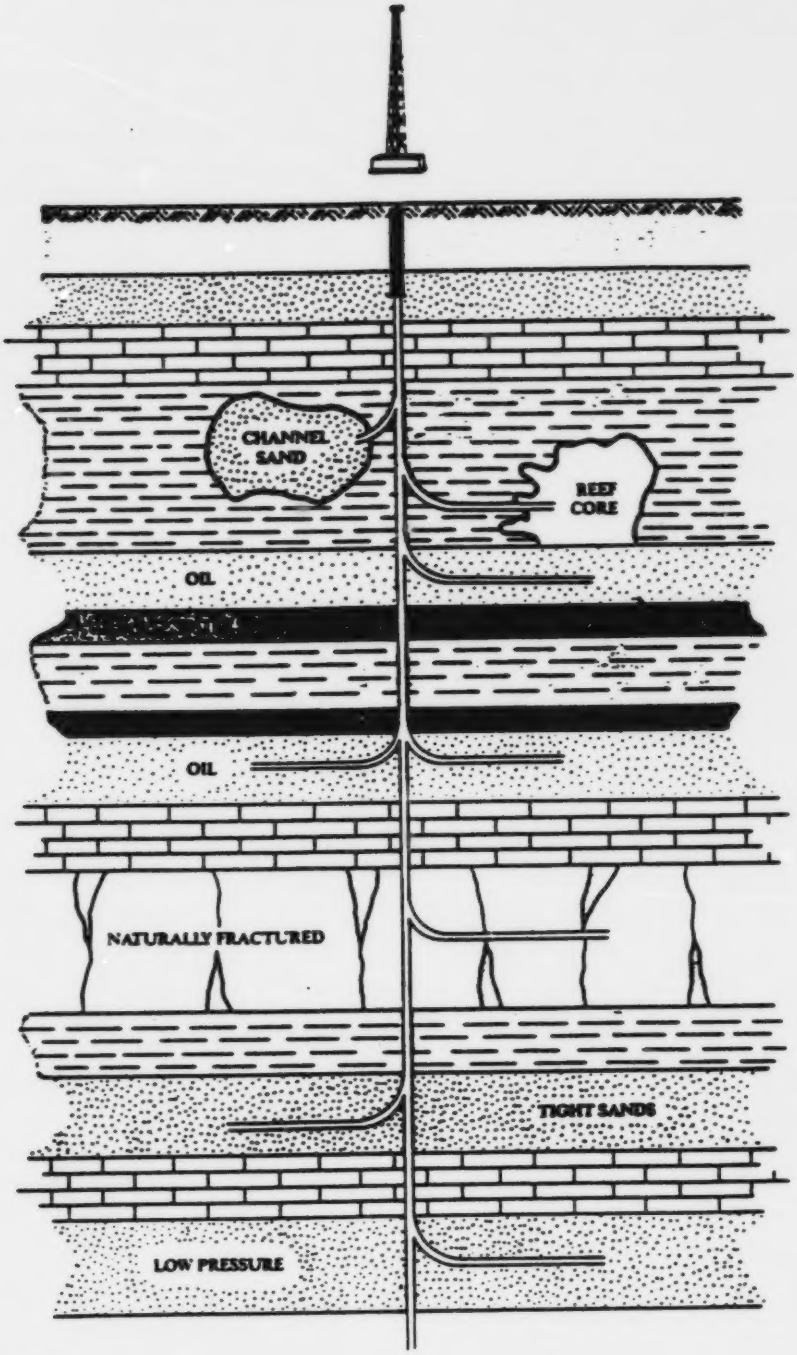
Increase production in low permeability formation through additional exposure to reservoir

Maximize production from low energy reservoir by increasing exposure to reservoir

SUGGESTED APPLICATIONS SUMMARY

BENEFITS	ALTERNATIVE TO FRACING	COAL SEAM METHANE	DISPOSAL WELL	SOLUTION MINING	GAS FIELD STORAGE	THERMAL FLOODING	CHEMICAL FLOODING	FLUID FLOODING	GAS FLOODING	PRIMARY PRODUCTION	EXPLORATION
	APPLICATIONS										
Increase Direct Contact With Formation											
• increase contact with pay zone	■	■	■	■	■	■	■	■	■	■	
• reach missed exploration targets	■			■						■	■
• cross numerous natural vertical fractures	■	■								■	■
• reach fractures in directions independent of local stress regime	■										
• create a high permeability streak in a "tight" formation	■			■						■	
• access formations subject to fracing damage	■									■	
• complete several laterals from a single well		■	■	■	■	■	■	■	■	■	■
• stay in formation of interest	■										
Replace Radial Drainage With Linear Drainage Along Lateral											
• optimize ultimate recovery	■			■		■	■	■	■	■	
• increase fluid production rate	■	■		■		■	■	■	■	■	
• increase gas production rate		■			■					■	
• increase recovery efficiency		■		■		■	■	■	■	■	
• improve sweep efficiency				■		■	■	■	■	■	
Reduce Pressure Gradient At Wellbore											
• conserve reservoir driving energy						■		■	■	■	
• minimize production of unwanted formation fluids (coning)	■					■		■		■	
• increase injection rates	■		■	■	■	■	■	■	■		
• improve downhole steam quality						■					
Improve Field Development Patterns											
• maximize well spacing	■	■		■	■					■	
• minimize infill drilling						■	■	■	■		
• optimize line flooding patterns						■	■	■	■		
• create direct communication between wells				■							

A PROBLEM SOLVING COMPLETION TECHNOLOGY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• reach missed exploration targets	■			■						■	■
• cross numerous natural vertical fractures	■	■								■	■
• reach fractures in directions independent of local stress regime	■										
• create a high permeability streak in a "tight" formation	■			■						■	
• access formations subject to fracing damage	■									■	
• complete several laterals from a single well		■	■	■	■	■	■	■	■	■	■
• stay in formation of interest	■										
Replace Radial Drainage With Linear Drainage Along Lateral											
• optimize ultimate recovery	■			■		■	■	■	■	■	
• increase fluid production rate	■	■		■		■	■	■	■	■	
• increase gas production rate		■			■					■	
• increase recovery efficiency		■		■		■	■	■	■	■	
• improve sweep efficiency				■		■	■	■	■	■	
Reduce Pressure Gradient At Wellbore											
• conserve reservoir driving energy						■		■	■	■	
• minimize production of unwanted formation fluids (coning)	■					■		■		■	
• increase injection rates	■		■	■	■	■	■	■	■		
• improve downhole steam quality						■					
Improve Field Development Patterns											
• maximize well spacing	■	■		■	■					■	
• minimize infill drilling						■	■	■	■		
• optimize line flooding patterns						■	■	■	■		
• create direct communication between wells				■							

SUMMARY

1. Experience

- 5-year development and use program
- Over 175 drainholes completed
- Over 50 wells completed with LCT
- Over 45,000 feet drilled horizontally
- 10,000 foot working depth
- 730 foot drainhole
- Temperature limitations:
  - 220° F standard tool set
  - 260° F+ special tool set
- Liner capabilities

2. Geologic formations drilled:

calcareous shales
siliceous shales
chalks
dolomite
limestone
siltstones
sandstones
conglomerates
evaporite beds

3. Applications

- Oil/gas wells
- Mining
- Fractured reservoirs
- Tight low energy reservoirs
- Unconsolidated reservoirs

PRELIMINARY PROPOSED CONDITIONS

I. Basis

- Cost given is per drainhole
- Operator to select number, orientation and length of drainhold
- Pay zone, well and drainhole parameters as given on the attached sheet*(s)*
- Operator to be responsible for preparing the well for LCT drilling
- Operator supplied equipment
    - Rig and associated equipment *(good weight indicator)*
    - Power swivel *(Bowen 3.5 or equal)*
    - Drill pipe and collars *(must be free of scale)*
    - Mud handling equipment and drilling fluid
    - Wireline equipment for single shot orientation
    - Gyro survey equipment for orientation if required
- TEDSI supplied equipment and service
    - Proprietary downhole tools
    - All survey equipment for drainhole surveying *(unless Gyro is required, see above)*
    - Supervisory crew to supervise LCT operations while using TEDSI's proprietary tools

PRELIMINARY PROPOSED CONDITIONS *(Continued)*

II. Conditions
  A. Operator may stop the turnkey operation at any time with the following provisions.
    1. If work ceases on any lateral _____ before _______ meters *(_____ feet)* of lateral has been drilled
      - full compensation if less than _____ days have elapsed
      - no compensation if more than _____ days have elapsed.
    2. If drilling under the meterage *(footage)* provision
      - full compensation of base price plus compensation of the additional meterage *(footage)* drilled
  B. TEDSI may stop the turnkey operation at any time with the following provisions.
    1. If work ceases on any lateral before _____ meters *(_____ feet)* of lateral has been drilled
      - no compensation for work performed and lateral completed
    2. If drilling under the meterage *(footage)* provision
      - full compensation of base price plus compensation of additional meterage *(footage)* drilled
  C. If TEDSI exercises its "Option B" above and operator elects to continue drilling
    1. TEDSI will continue drilling under day rate provisions excluding day rate mobilization
    2. Lost tool cost will be considered under conditions which are believed to result in lost tools
  D. If TEDSI operates on a day rate basis there is no guarantee of drilling performance
  E. TEDSI will not charge for lost tools if TEDSI is allowed to "fish" for lost tools, TEDSI's option
  F. If TEDSI options to "fish" for lost tools TEDSI will pay for fishing cost

FORMATION, WELL AND DRAINHOLE INFORMATION SHEET

1. Reference Number/Name:
2. Pay zone characteristics
   - A. Depth:
   - B. Thickness:
   - C. Dip:
   - D. Type of rock:
   - E. Temperature:
   - F. Normal drilling rate:
     Weight, bit size, drilling fluid:
     Production:
3. Well information
   - A. Existing well or new well:
   - B. Window, openhole or bottom KOP:
   - C. Casing size and weight:
4. Drainhole requirements
   - A. Number required:
   - B. KOP or TVD of DH:
   - C. Length desired:
   - D. Size desired:
   - E. Azimuth & azimuth variance:
   - F. Inclination & inclination variance:
5. Miscellaneous information:
   - A. Drilling fluid desired:
   - B. Completion requirements:
   - C. Other pertinent data:

47.

Eastman Whipstock

____/____/____
Date

Lateral Drilling Information

____
Eastman Whipstock Representative

Company I.D. ____________________
Address ____________________
Key Contact ____________________
Phone No. ____________________
Field Foreman ____________________
Office Engineer ____________________
Well I.D. ____________________
Field ____________________
County ____________________
State ____________________
Nearest City ____________________
Section ____________________
Township ____________________
Range ____________________
Surface ____________________ F__L
Surface ____________________ F__L
Drilling Contractor __________(__)__________
Tool Pusher __________(__)__________
Rig Depth Rating ____________________
Stand Length S______ D______ T______
Rig I.D. __________(__)__________
K.B. Elevation ____________________
Mud Pump Type ____________________
Type Of B.O.P. Stack ____________________
Drill Pipe Type______ Size______ T.J.______
Drill Collars Type______ Size______ T.J.______
N.M.D.C. Lenght______ Size______ T.J.______
Minimum String I.D. ____________________
Power Swivel Type ____________________

Type Of Rock ____________________
Formation Name ____________________
Top Of Zone ____________________
Bottom Of Zone ____________________
Thickness Of Zone ____________________
Dip Angle ____________________
Up Dip Direction ____________________
Temperature Static__________ Circ.__________
Vertical Drill Rate:
______F.P.M. With ______ W.O.B. And ______ R.P.M.
Bit Type ______Bit Make ______Jet Size ______
______F.P.M. With ______ W.O.B. And ______ R.P.M.
Bit Type ______Bit Make ______Jet Size ______

Well Status New______ Existing______
Cased Through Zone Or Open Hole ____________________

	Surface	Intermediate	Production
Casing Type			
Casing Size			
Casing Weight			
Casing Depth			
Casing I.D.			

Well T.V.D. ____________________
Washouts Y_____N_____ Depths ____________________
Doglegs Y_____N_____ Depths ____________________
Caliper Log Available Y_____ N_____
Inclination At K.O.P. ____________________
Direction At K.O.P. ____________________
Survey Report Available Y_____ N_____

Number Of Laterals ______ Start Date __/__/__
T.V.D. Of Laterals ______ ______ ______
Lateral Hole Size ______ ______ ______
Lateral Direction ______ ______ ______
Direction +/- ______ ______ ______
Lateral Inclination ______ ______ ______
Inclination +/- ______ ______ ______
Length Of Laterals ______ ______ ______

Type Of Kick O.H.M.____B.H.M.____L.M.____O.G.M.____
Type Of Surveys Gyro__________ Mag.__________
Latitude Of Job Location ____________________
Wireline Unit Available ____________________
North Definition ____________________
Mag. Declination ____________________
Drilling Fluid Desired ____________________
Additional Comments On Reverse Side.

Drainhole Report

Date ______________ Report Number ______________ Lease No. ______________ Hole Number ______________

Drain Hole Number ______________________________ Rig Number ______________________________

MUD TYPE: WT: VIS: FILTRATE: % SAND: % OIL:

AIR P.S.I.: C.F.M.: BOOSTER TYPE/SIZE: COMPRESSOR TYPE/SIZE:

MIST-INJECT G.P.H.: FOAM INJECT G.P.H.: MIX:

REMARKS:

Note: Include All Serial Numbers of Drill Guides and Drive Pipe.

B.H.A. NO.:	BIT NO.:	BIT SIZE & TYPE:		JETS:	
BIT +	+	+	+	+	+
+	+	+	+	+	+
+	+	+	+	+	LENGTH:
B.H.A. NO.:	BIT NO.:	BIT SIZE & TYPE:		JETS:	
BIT +	+	+	+	+	+
+	+	+	+	+	+
+	+	+	+	+	LENGTH:
B.H.A. NO.:	BIT NO.:	BIT SIZE & TYPE:		JETS:	
BIT +	+	+	+	+	+
+	+	+	+	+	+
+	+	+	+	+	LENGTH:

TO BE FILLED OUT HOURLY

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Hole Depth																								
Penet. Ft/Hr.																								
Wt. on Bit																								
R.P.M.																								
Torque																								
P.S.I.																								
G.P.H.																								
C.F.M.																								

KOP. DESIRED DIRECTION: DESIRED ANGLE:

RIG PUMPS-TYPE: SIZE: HORSEPOWER:

T.D. AT 24:00 HRS.: FOOTAGE IN 24:00 HOURS: DRILLING HOURS: SURVEY HOURS: OTHER HOURS:

REMARKS: Include Any Change in Torque or PSI and at What Depth. Use Back of Sheet If Necessary.

Time			
FM	TO	ELP	